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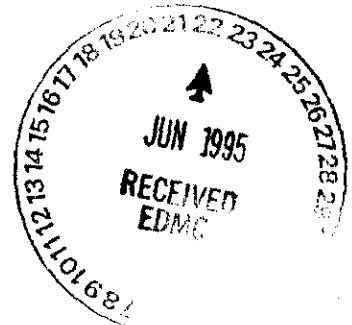
Hanford Site National Environmental Policy Act (NEPA) Characterization

C. E. Cushing, Editor

August 1994

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
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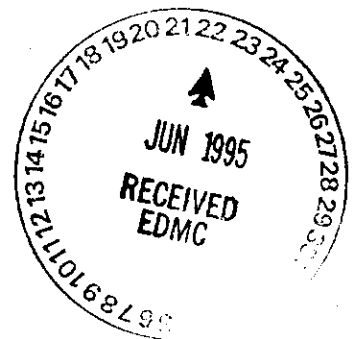
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Preface

This document describes the Hanford Site environment (Chapter 4.0) and contains data in Chapters 5.0 and 6.0 that will assist users in the preparation of National Environmental Policy Act- (NEPA-) related documents.

Many NEPA compliance documents have been prepared and are being prepared by site contractors for the U.S. Department of Energy (DOE), and examination of these documents reveals inconsistencies in the data presented and the method of presentation. Thus, it seemed necessary to prepare a consistent description of the Hanford Site environment to be used in preparing Chapter 4.0 of environmental impact statements and other site-related NEPA documentation. The material in Chapter 5.0 is a guide to the models used, including critical assumptions incorporated in these models in previous Hanford NEPA documents. The user will have to select those models appropriate for the proposed action. Chapter 6.0 is essentially a definitive NEPA Chapter 6.0, which describes applicable federal and state laws and regulations.

In this document, a complete description of the environment is presented in Chapter 4.0 without extensive tabular data. For these data, sources are provided. Most subjects are divided into a general description of the characteristics of the Hanford Site, followed by site-specific information where it is available on the 100, 200, 300, and other Areas. This division will allow a person requiring information to go immediately to those sections of particular interest. However, site-specific information on each of these separate areas is not always complete or available. In this case, the general Hanford Site description should be used.

To enhance the usability of the document, a copy of the entire text is available on an IBM PC diskette in WordPerfect 5.1 on request to C. E. Cushing at (509) 376-9670. Macintosh diskettes are also available (WordPerfect). The figures can be obtained by contacting the Boeing Company Services Richland (BCSR) Graphics Department, located in the Pacific Northwest Laboratory Sigma I Building and using the classification number in the lower right corner of each figure. Janelle Downs kindly provided Figure 4.3-1.

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Summary

This sixth revision of the Hanford Site National Environmental Policy (NEPA) Characterization presents current environmental data regarding the Hanford Site and its immediate environs. This information is intended for use in preparing Site-related NEPA documentation.

Chapter 4.0 summarizes up-to-date information on climate and meteorology, geology and hydrology, ecology, history and archaeology, socioeconomics, land use, and noise levels prepared by Pacific Northwest Laboratory (PNL) staff. More detailed data are available from reference sources cited or from the authors.

Chapter 5.0 has been significantly updated from the fifth revision (1992). It describes models, including their principal underlying assumptions, that are to be used in simulating realized or potential impacts from nuclear materials at the Hanford Site. Included are models of radionuclide transport in groundwater and atmospheric pathways, and of radiation dose to populations via all known pathways from known initial conditions.

The updated Chapter 6.0 provides the preparer with the federal and state regulations, DOE orders and permits, and environmental standards directly applicable to the NEPA documents on the Hanford Site, following the structure of Chapter 4.0.

No conclusions or recommendations are given in this report. Rather, it is a compilation of information on the Hanford Site environment that can be utilized directly by Site contractors. This information can also be used by any interested individual seeking baseline data on the Hanford Site and its past activities by which to evaluate projected activities and their impacts.

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4.0 Affected Environment

The U. S. Department of Energy's Hanford Site lies within the semiarid Pasco Basin of the Columbia Plateau in southeastern Washington State (Figures 4.0-1 and 4.0-2). The Hanford Site occupies an area of about 1450 km² (~560 mi²) north of the confluence of the Snake and Yakima rivers with the Columbia River. The Hanford Site is about 50 km (30 mi) north to south and 40 km (24 mi) east to west. This land, with restricted public access, provides a buffer for the smaller areas currently used for storage of nuclear materials, waste storage, and waste disposal; only about 6% of the land area has been disturbed and is actively used. The Columbia River flows through the northern part of the Hanford Site and, turning south, forms part of the Site's eastern boundary. The Yakima River runs along part of the southern boundary and joins the Columbia River below the city of Richland, which bounds the Hanford Site on the southeast. Rattlesnake Mountain, the Yakima Ridge, and the Umtanum Ridge form the southwestern and western boundaries. The Saddle Mountains form the northern boundary of the Hanford Site. Two small east-west ridges, Gable Butte and Gable Mountain, rise above the plateau of the central part of the Hanford Site. Adjoining lands to the west, north, and east are principally range and agricultural land. The cities of Richland, Kennewick, and Pasco (Tri-Cities) constitute the nearest population center and are located southeast of the Hanford Site.

The Hanford Site encompasses more than 1500 waste management units and four groundwater contamination plumes that have been grouped into 73 operable units. Each unit has complementary characteristics of such parameters as geography, waste content, type of facility, and relationship of contaminant plumes. This grouping into operable units allows for economies of scale to reduce the cost and number of characterization investigations and remedial actions that will be required for the Hanford Site to complete cleanup efforts (WHC 1989). The 73 operable units have been aggregated into four areas: 22 in the 100 Area, 43 in the 200 Areas, 5 in the 300 Area, and 4 in the 1100 Area. There are an additional 4 units in the 600 Area Isolated Waste Site Area (WHC 1989). Those persons contemplating NEPA-related activities on the Hanford Site should be aware of the existence and location of the various operable units. Current maps showing the locations of the operable units can be obtained from Westinghouse Hanford Company, Environmental Restoration Program Office.

4.1 Climate and Meteorology

The Hanford Site is located in a semiarid region of southeastern Washington State. The Cascade Mountains, beyond Yakima to the west, greatly influence the climate of the Hanford area by means of their "rain shadow" effect; this mountain range also serves as a source of cold air drainage, which has a considerable effect on the wind regime on the Hanford Site.

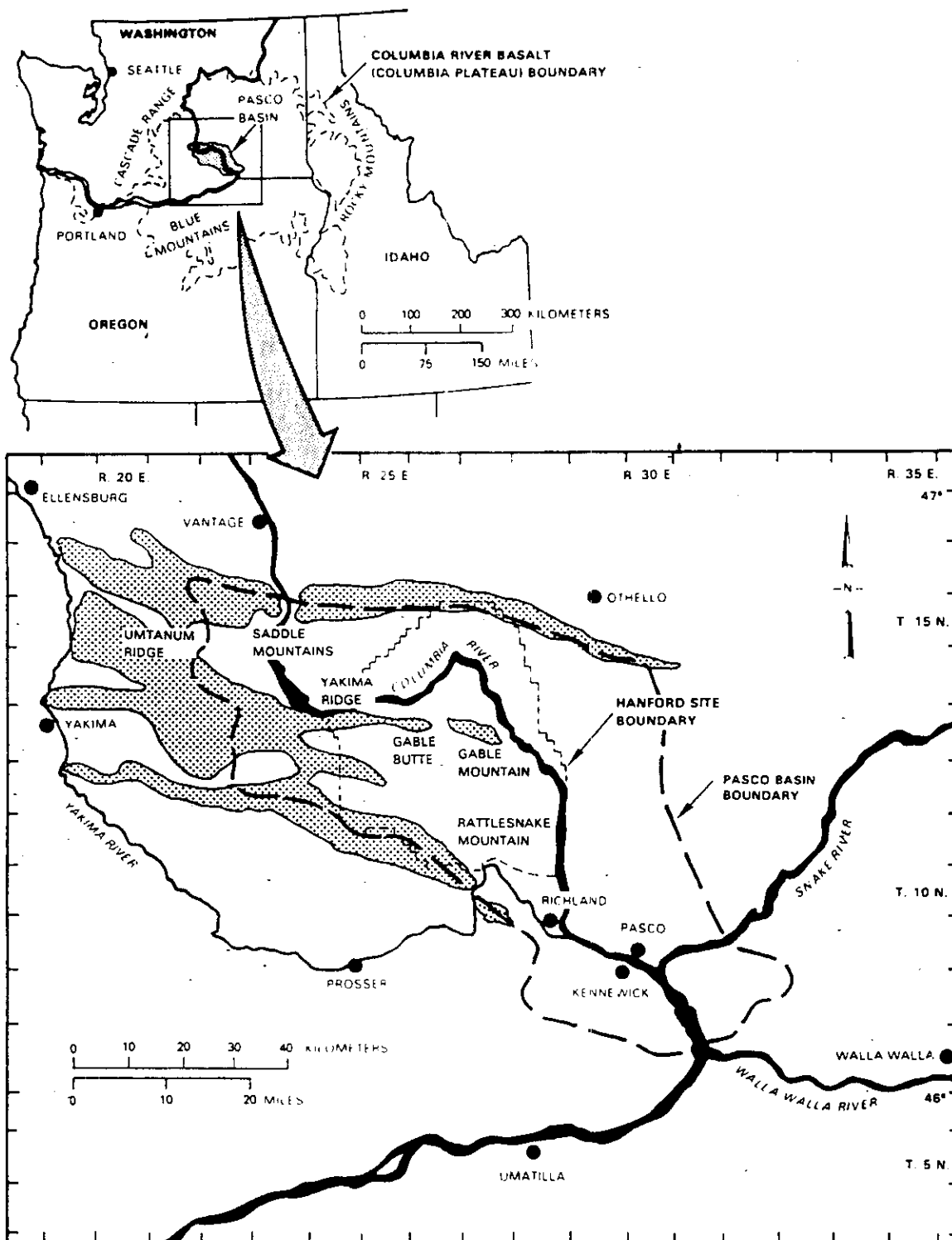


Figure 4.0-1. Hanford Site and Environs. Stippled areas denote basalt outcroppings.

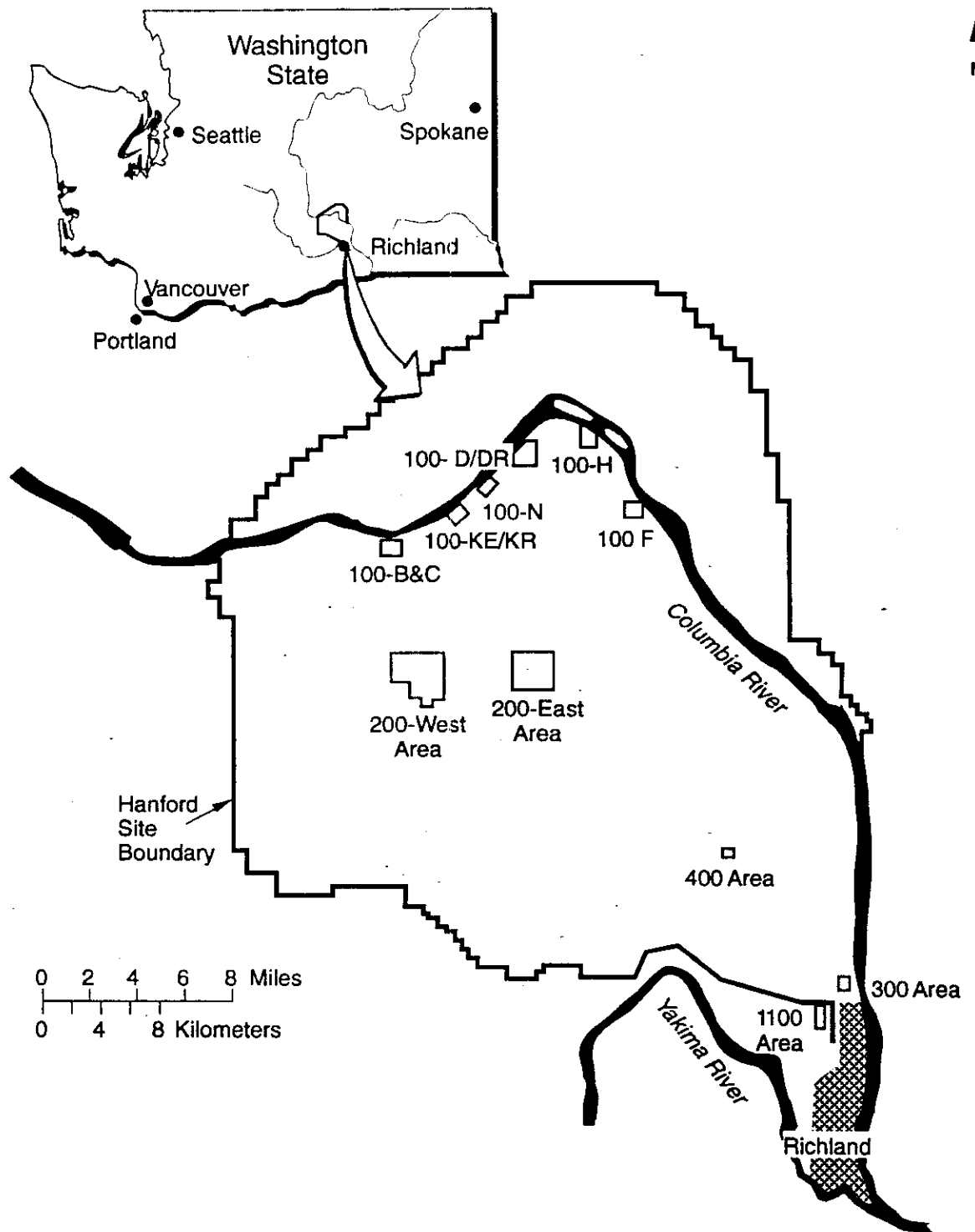


Figure 4.0-2. Hanford Site map.

Climatological data are available for the Hanford Meteorological Station (HMS), which is located between the 200-East and 200-West areas. Data have been collected at this location since 1945. Temperature and precipitation data are also available from nearby locations for the period 1912 through 1943. A summary of these data through 1980 has been published by Stone et al. (1983). Data from the HMS are representative of the general climatic conditions for the region and describe the specific climate of the 200-Area Plateau. Local variations in the topography of the Hanford Site may cause some aspects of climate at portions of the Hanford Site to differ significantly from those of the HMS. For example, winds near the Columbia River are different than those at the HMS. Similarly, precipitation along the slopes of the Rattlesnake Hills differs climatically from that at the HMS.

4.1.1 Wind

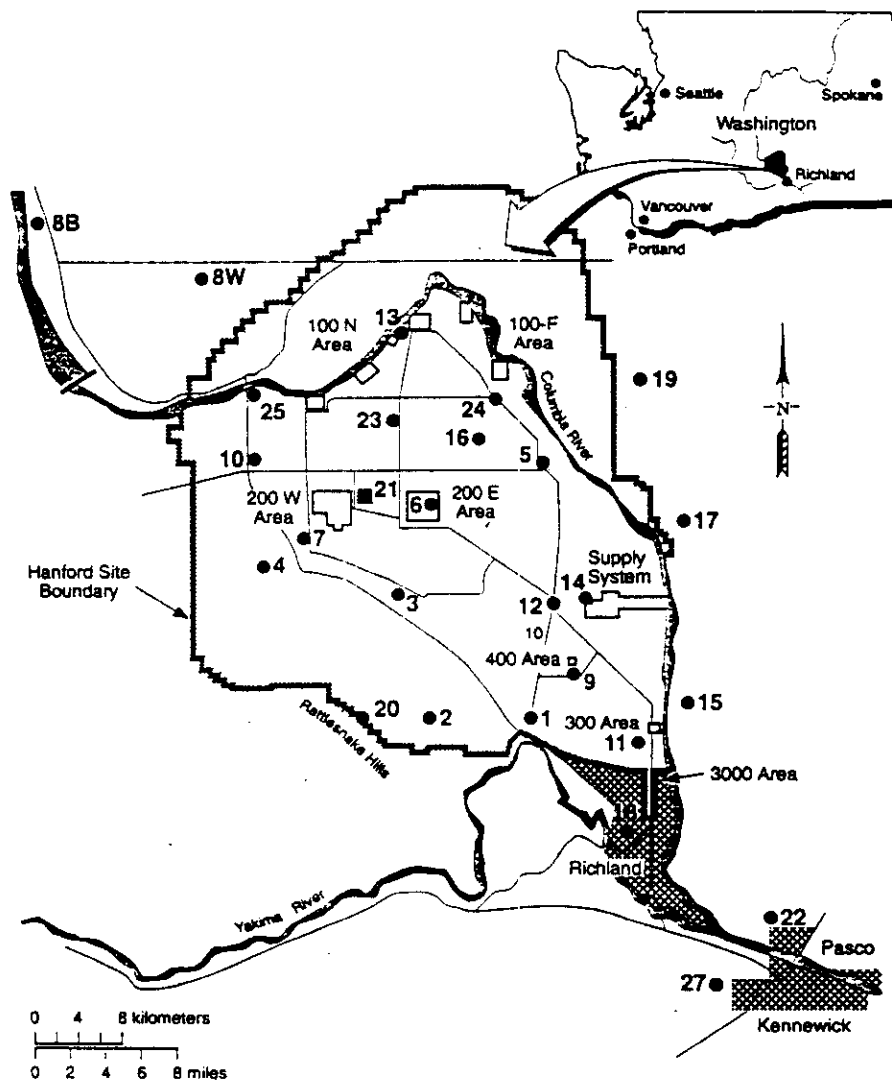
Wind data are collected at the HMS at the surface (2.1 m, ~7 ft above ground) and at the 15.2-, 30.5-, 61.0-, 91.4-, and 121.9-m levels of a 125-m tower. Three 60-m towers, with wind-measuring instrumentation at the 10-, 25-, and 60-m levels, are located at the 300, 400, and 100-N Areas. In addition, wind instruments on twenty-one 9.1-m towers distributed on and around the Hanford Site (Figure 4.1-1) provide supplementary data for defining wind patterns. Instrumentation on each of the towers is described in Table 4.1-1.

Prevailing wind directions on the 200-Area Plateau are from the northwest in all months of the year (Figure 4.1-2). Secondary maxima occur for southwesterly winds. Summaries of wind direction indicate that winds from the northwest quadrant occur most often during the winter and summer. During the spring and fall, the frequency of southwesterly winds increases with a corresponding decrease in northwest flow. Winds blowing from other directions (e.g., northeast) display minimal variation from month to month.

Monthly and annual joint-frequency distributions of wind direction versus wind speed for the HMS are given in Stone et al. (1983). Monthly average wind speeds are lowest during the winter months, averaging 10 to 11 km/h (6 to 7 mi/h), and highest during the summer, averaging 14 to 16 km/h (8 to 10 mi/h). Wind speeds that are well above average are usually associated with southwesterly winds. However, the summertime drainage winds are generally northwesterly and frequently reach 50 km/h (30 mi/h). These winds are most prevalent over the northern portion of the Hanford Site.

4.1.2 Temperature and Humidity

Temperature measurements are made at the 0.9-, 9.1-, 15.2-, 30.5-, 61.0-, 76.2-, 91.4-, and 121.9-m levels of the 125-m (400-ft) tower at the HMS. As of March 1994, temperatures are also measured at the 2-m level on the twenty-one 9.1-m towers located on and around the Hanford Site. The three 60-m (197-ft) towers have temperature-measuring instrumentation at the 2-, 10-, and 60-m (~6.5-, 33-, and 197-ft) levels. The temperature data from the 9.1- and 60-m (30 and 197-ft) towers are telemetered to the HMS.



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Figure 4.1-1. Hanford Site wind monitoring network.

Station No.	Station Name	Station No.	Station Name
1	Prosser Barricade	14	WPPSS
2	EOC	15	Franklin County
3	Army Loop Road	16	Gable Mountain
4	Rattlesnake Springs	17	Ringold
5	Edna	18	Richland Airport
6	200-East	19	Sagehill
7	200-West	20	Rattlesnake Mtn.
8	Wahluke Slope	21	HMS (121.9-m)
9	FFTF (60-m)	22	Pasco Airport
10	Yakima Barricade	23	Gable West
11	300 Area (60-m)	24	100-F
12	Wye Barricade	25	Vernita
13	100-N (60-m)	27	Vista

NOTE: All network stations are 9.1 m (~30 ft) unless otherwise indicated.

Table 4.1-1. Station numbers, names, and instrumentation for each Hanford meteorological monitoring site.

Site Number	Site Name	Instrumentation
1	Prosser Barricade	WS, WD, T, P
2	EOC	WS, WD, T, P
3	Army Loop Road	WS, WD, T, P
4	Rattlesnake Springs	WS, WD, T, P
5	Edna	WS, WD, T
6	200-East	WS, WD, T, P
7	200-West	WS, WD, T, P
8B	Beverly	WS, WD, T, P
8W*	Wahluke Slope	WS, WD, T, P
9	FFTF (60-m)	WD, T, TD, DP, P, AP
10	Yakima Barricade	WS, WD, T, P, AP
11	300 Area (60-m)	WS, WD, T, TD, DP, P
12	Wye Barricade	WS, WD, T, P
13	100-N (60-m)	WS, WD, T, TD, DP, AP
14	Supply System	WS, WD, T, P
15	Franklin County	WS, WD, T
16	Gable Mountain	WS, WD, T
17	Ringold	WS, WD, T
18	Richland Airport	WS, WD, T, AP
19*	Sagehill	WS, WD, T
20	Rattlesnake Mountain	WS, WD, T, P
21	Hanford Meteorology Station	WS, WD, T, P
22	Pasco	WS, WD, T
23	Gable West	WS, WD, T
24	100-F	WS, WD, T, P
25	Vernita Bridge	WS, WD, T
26	Test Station (spare)	WS, WD, T, P, AP
27	Vista	WS, WD, T
28	Roosevelt	WS, WD, T

Legend: WS - Wind speed
WD - Wind direction
T - Temperature
TD - Temperature difference
DP - Dewpoint temperature
P - Precipitation
AP - Atmospheric pressure

* Station no longer active.

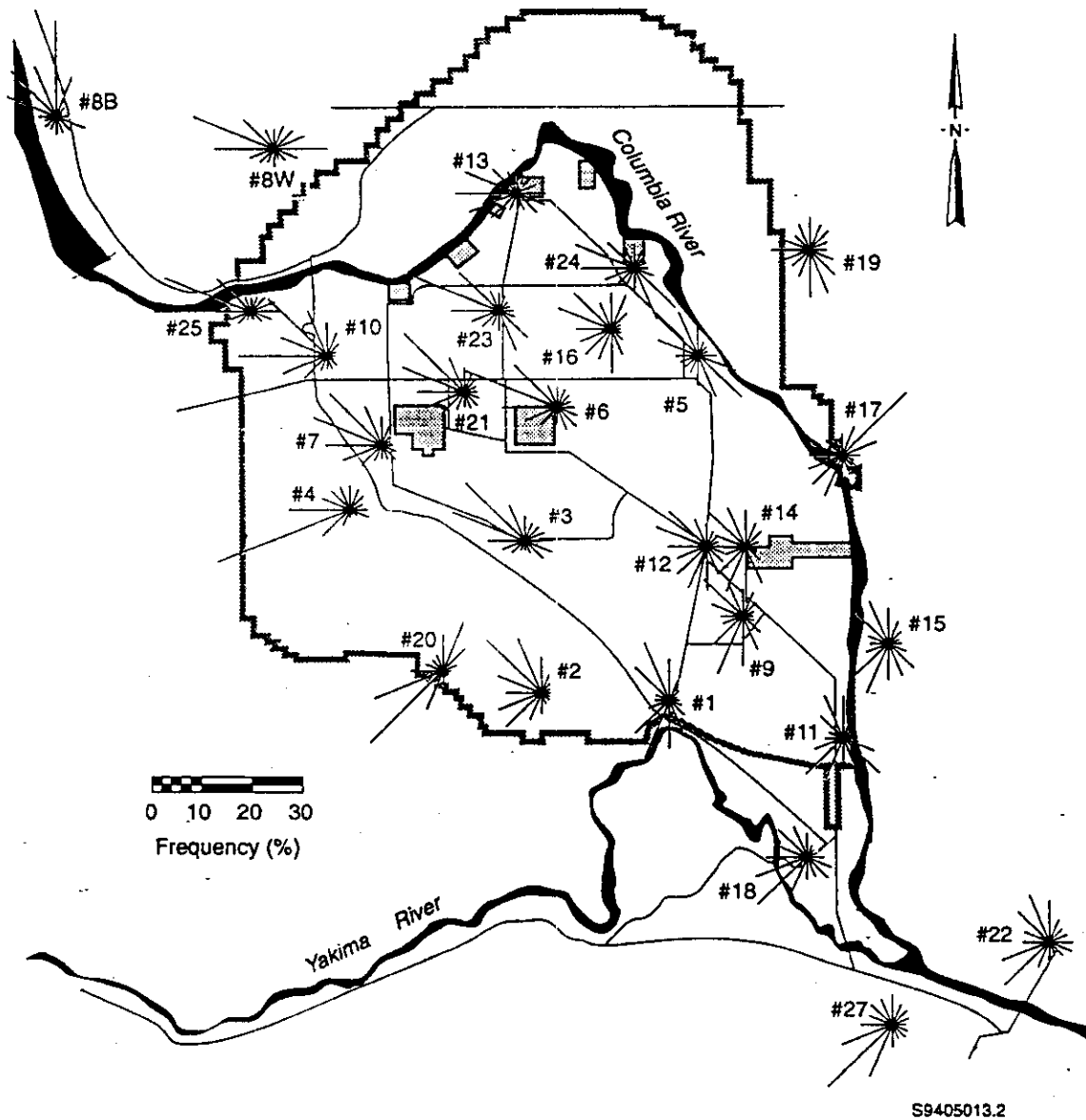


Figure 4.1-2. Wind roses for the Hanford telemetry network, 1979-1988. The point of each rose represents the directions from which the winds come.

Diurnal and monthly averages and extremes of temperature, dew point, and humidity are contained in Stone et al. (1983). Ranges of daily maximum temperatures vary from normal maxima of 2°C (36°F) in early January to 35°C (95°F) in late July. There are, on the average, 51 days during the summer months with maximum temperatures $\geq 32^\circ\text{C}$ (90°F) and 12 days with maxima greater than or equal to 38°C (100°F). From mid-November through mid-March, minimum temperatures average $\leq 0^\circ\text{C}$ (32°F) with the minima in early January averaging -6°C (21°F). During the winter, there are, on average, 3 days with minimum temperatures $\leq -18^\circ\text{C}$ (~0°F); however, only about one winter in two experiences such temperatures. The record maximum temperature is 45°C (113°F), and the record minimum temperature is -31°C (-24°F). For the period 1946 through 1993, the average monthly temperatures range from a low of -0.9°C (30°F) in January to a high of 24.6°C (76°F) in July. During the winter, the highest monthly average temperature at the HMS was 6.9°C (44°F) in February, and the record lowest was -11.1°C (12°F) during January. During the summer, the record maximum monthly average temperature was 27.9°C (82°F) (in July), and the record lowest was 17.2°C (63°F) (in June).

Relative humidity/dew point temperature measurements are made at the HMS and at the three 60-m (200-ft) tower locations. The annual average relative humidity at the HMS is 54%. It is highest during the winter months, averaging about 75%, and lowest during the summer, averaging about 35%. Wet bulb temperatures $> 24^\circ\text{C}$ (75°F) had not been observed at the HMS before 1975; however, on July 8, 9, and 10 of that year, there were seven hourly observations with wet bulb temperatures $\geq 24^\circ\text{C}$ (75°F).

4.1.3 Precipitation

Precipitation measurements have been made at the HMS since 1945. Average annual precipitation at the HMS is 16 cm (6.3 in.). Most precipitation occurs during the winter with more than half of the annual amount occurring in the months of November through February. Days with > 1.3 cm (.51 in.) precipitation occur less than 1% of the year. Rainfall intensities of 1.3 cm/h (.51 in./h) persisting for 1 hour are expected once every 10 years. Rainfall intensities of 2.5 cm/h (1 in./h) for 1 hour are expected only once every 500 years. Winter monthly average snowfall ranges from 0.8 cm (.32 in.) in March to 14.5 cm (6 in.) in December. The record monthly snowfall of 62 cm (24 in.) occurred in February 1916. The seasonal record snowfall of 142 cm (56 in.) occurred during the winter of 1992-1993. Snowfall accounts for about 38% of all precipitation during the months of December through February.

Climatological precipitation measurements have also been made on the Fitzner-Eberhardt Arid Lands Ecology Reserve on the northeast slope of the Rattlesnake Hills (Stone et al. 1983).

4.1.4 Fog and Visibility

Fog has been recorded during every month of the year at the HMS; however, 95% of the occurrences are during the months of November through February, with less than 1% during the months of April through September (Table 4.1-2). The average number of days per year with fog (visibility less than or equal to 9.6 km or 6 mi) is 46, and with dense fog

(visibility less than or equal to 0.4 km or 0.25 mi), 24. The greatest number of days with fog was 84 days in 1985-1986 and the least 22 in 1948-1949; the greatest number of days with dense fog was 42 days in 1950-1951, and the least, 9 days in 1948-1949. The greatest persistence of fog was 114 hours (December 1985), and the greatest persistence of dense fog was 47 hours (December 1957).

Other phenomena causing restrictions to visibility (i.e., visibility ≤ 9.6 km [6 mi]) include dust, blowing dust, and smoke from field burning. There are few such days; an average of 5 days per year have dust or blowing dust and < 1 day per year has reduced visibility from smoke.

4.1.5 Severe Weather

High winds are also associated with thunderstorms. The average occurrence of thunderstorms is 10 per year. They are most frequent during the summer; however, they have occurred in every month. The average winds during thunderstorms come from no specific direction. Estimates of the extreme winds, based on peak gusts observed from 1945 through 1980, are given in Stone et al. (1983) and are shown in Table 4.1-3. Using the National Weather Service criteria for classifying a thunderstorm as "severe" (i.e., hail with a diameter ≥ 20 mm (1 in.) or wind gusts of ≥ 93 km/h [58 mi/h]), only 1.9% of all thunderstorm events observed at the HMS have been "severe" storms, and all met the criteria based on wind gusts.

Tornadoes are infrequent and generally small in the northwest portion of the United States. Grazulis (1984) lists no violent tornadoes for the region surrounding Hanford (DOE 1987). The HMS climatological summary (Stone et al. 1983) and the National Severe Storms Forecast Center (NSSFC) database list 22 separate tornado occurrences within 161 km (100 mi) of the Hanford Site from 1916 through August 1982. Two additional tornadoes have been reported since August 1982.

Table 4.1-2. Number of days with fog by season.

<u>Category</u>	<u>Winter</u>	<u>Spring</u>	<u>Summer</u>	<u>Autumn</u>	<u>Total</u>
Fog	32	2	$\leq 1/2$	12	46
Dense fog	17	1	$\leq 1/2$	6	24

Table 4.1-3. Estimates of extreme winds at the Hanford Site.

Return period (yr)	Peak gusts (km/h)	
	15.2 m above ground	61 m above ground
2	97	109
10	114	129
100	137	151
1000	159	75

Using the information in the preceding paragraph and the statistics published in Ramsdell and Andrews (1986) for the 5° block centered at 117.5° west longitude and 47.5° north latitude (the area in which the Hanford Site is located), the expected path length of a tornado on the Hanford Site is 7.6 km (5 mi), the expected width is 95 m (312 ft), and the expected area is about 1.5 km² (1 mi²). The estimated probability of a tornado striking a point at Hanford, also from Ramsdell and Andrews (1986), is 9.6×10^{-6} /yr. The probabilities of extreme winds associated with tornadoes striking a point can be estimated using the distribution of tornado intensities for the region. These probability estimates are given in Table 4.1-4.

4.1.6 Atmospheric Dispersion

Atmospheric dispersion is a function of wind speed, duration and direction of wind, atmospheric stability, and mixing depth. Dispersion conditions are generally good if winds are moderate to strong, if the atmosphere is of neutral or unstable stratification, and if there is a deep mixing layer. Good dispersion conditions associated with neutral and unstable stratification exist about 57% of the time during the summer. Less favorable dispersion conditions may occur when the wind speed is light and the mixing layer is shallow. These conditions are most common during the winter when moderately to

Table 4.1-4. Estimate of the probability of extreme winds associated with tornadoes striking a point at Hanford^(a).

Wind speed (km/h)	Probability per year
100	2.6×10^{-6}
200	6.5×10^{-7}
300	1.6×10^{-7}
400	3.9×10^{-8}

(a) Ramsdell and Andrews (1986).

extremely stable stratification exists about 66% of the time. Less favorable conditions also occur periodically for surface and low-level releases in all seasons from about sunset to about an hour after sunrise as a result of ground-based temperature inversions and shallow mixing layers. Mixing-layer thicknesses have been estimated at the HMS using remote sensors. The variations in mixing layer described previously are summarized in Table 4.1-5.

Occasionally there are extended periods of poor dispersion conditions associated with stagnant air in stationary high-pressure systems that occur primarily during the winter months. Stone et al. (1972) estimated the probability of extended periods of poor dispersion conditions. The probability of an inversion period extending more than 12 hours varies from a low of about 10% in May and June to a high of about 64% in September and October. These probabilities decrease rapidly for durations of > 12 hours. Table 4.1-6 summarizes the probabilities associated with extended surface-based inversions.

Annual average atmospheric diffusion factors (X/Q') have been computed at the Skagit-Hanford Site, the 200-East Area, and the 400 Area using 1983 through 1987 meteorological data. These diffusion factors are presented in Tables 4.1-7 through 4.1-9 as a function of direction and distance from the facility. Table 4.1-7, for the Skagit-Hanford Site, shows ground-level releases. Tables 4.1-8 and 4.1-9, for the 200-East Area, present diffusion

Table 4.1-5. Percent frequency of occurrence of mixing-layer thickness by season and time of day.

<u>Mixing layer (m)</u>	<u>Winter</u>		<u>Summer</u>	
	<u>Night</u>	<u>Day</u>	<u>Night</u>	<u>Day</u>
< 250	65.7	35.0	48.5	1.2
250-500	24.7	39.8	37.1	9.0
> 500	9.6	25.2	14.4	89.9

Table 4.1-6. Percent probabilities for extended periods of surface-based inversions.

<u>Months</u>	<u>Inversion duration</u>		
	<u>12 hr</u>	<u>24 h</u>	<u>48 h</u>
January-February	54.0	2.5	0.28
March-April	50.0	<0.1	<0.1
May-June	10.0	<0.1	<0.1
July-August	18.0	<0.1	<0.1
September-October	64.0	0.11	<0.1
November-December	50.0	1.2	0.13

Table 4.1-7. Annual average atmospheric diffusion factors (χ/Q') for the Skagit-Hanford Site for ground-level release based on 1983-1987 data.

	$\chi/Q' \text{ (s/m}^3\text{)}$									
	0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	5.62×10^{-6}	8.82×10^{-7}	4.03×10^{-7}	2.44×10^{-7}	1.70×10^{-7}	8.19×10^{-8}	3.13×10^{-8}	1.56×10^{-8}	9.94×10^{-9}	7.11×10^{-9}
NNE	5.39×10^{-6}	8.48×10^{-7}	3.88×10^{-7}	2.36×10^{-7}	1.64×10^{-7}	7.95×10^{-8}	3.05×10^{-8}	1.53×10^{-8}	9.74×10^{-9}	6.98×10^{-9}
NE	5.39×10^{-6}	8.49×10^{-7}	3.89×10^{-7}	2.37×10^{-7}	1.64×10^{-7}	7.96×10^{-8}	3.05×10^{-8}	1.53×10^{-8}	9.74×10^{-9}	6.98×10^{-9}
ENE	6.00×10^{-6}	9.46×10^{-7}	4.34×10^{-7}	2.64×10^{-7}	1.84×10^{-7}	8.89×10^{-8}	3.41×10^{-8}	1.71×10^{-8}	1.09×10^{-8}	7.83×10^{-9}
E	7.12×10^{-6}	1.13×10^{-6}	5.19×10^{-7}	3.16×10^{-7}	2.20×10^{-7}	1.07×10^{-7}	4.12×10^{-8}	2.07×10^{-8}	1.32×10^{-8}	9.50×10^{-9}
ESE	1.08×10^{-5}	1.72×10^{-6}	7.90×10^{-7}	4.81×10^{-7}	3.35×10^{-7}	1.63×10^{-7}	6.27×10^{-8}	3.15×10^{-8}	2.01×10^{-8}	1.44×10^{-8}
SE	1.38×10^{-5}	2.19×10^{-6}	1.00×10^{-6}	6.10×10^{-7}	4.24×10^{-7}	2.05×10^{-7}	7.84×10^{-8}	3.92×10^{-8}	2.49×10^{-8}	1.78×10^{-8}
SSE	7.92×10^{-6}	1.25×10^{-6}	5.68×10^{-7}	3.44×10^{-7}	2.39×10^{-7}	1.15×10^{-7}	4.36×10^{-8}	2.17×10^{-8}	1.38×10^{-8}	9.83×10^{-9}
S	7.15×10^{-6}	1.11×10^{-6}	5.02×10^{-7}	3.03×10^{-7}	2.09×10^{-7}	9.94×10^{-8}	3.73×10^{-8}	1.84×10^{-8}	1.16×10^{-8}	8.24×10^{-9}
SSW	2.69×10^{-6}	4.14×10^{-7}	1.86×10^{-7}	1.12×10^{-7}	7.72×10^{-8}	3.67×10^{-8}	1.37×10^{-8}	6.73×10^{-9}	4.24×10^{-9}	3.01×10^{-9}
SW	2.54×10^{-6}	3.92×10^{-7}	1.76×10^{-7}	1.06×10^{-7}	7.28×10^{-8}	3.45×10^{-8}	1.28×10^{-8}	6.30×10^{-9}	3.96×10^{-9}	2.81×10^{-9}
WSW	2.44×10^{-6}	3.75×10^{-7}	1.69×10^{-7}	1.01×10^{-7}	6.98×10^{-8}	3.31×10^{-8}	1.23×10^{-8}	6.06×10^{-9}	3.82×10^{-9}	2.71×10^{-9}
W	2.87×10^{-6}	4.38×10^{-7}	1.97×10^{-7}	1.18×10^{-7}	8.13×10^{-8}	3.86×10^{-8}	1.44×10^{-8}	7.08×10^{-9}	4.47×10^{-9}	3.18×10^{-9}
WNW	4.23×10^{-6}	6.50×10^{-7}	2.94×10^{-7}	1.77×10^{-7}	1.22×10^{-7}	5.85×10^{-8}	2.20×10^{-8}	1.09×10^{-8}	6.91×10^{-9}	4.93×10^{-9}
NW	5.78×10^{-6}	9.00×10^{-7}	4.09×10^{-7}	2.47×10^{-7}	1.71×10^{-7}	8.17×10^{-8}	3.08×10^{-8}	1.53×10^{-8}	9.67×10^{-9}	6.90×10^{-9}
NNW	5.87×10^{-6}	9.20×10^{-7}	4.19×10^{-7}	2.54×10^{-7}	1.76×10^{-7}	8.49×10^{-8}	3.23×10^{-8}	1.61×10^{-8}	1.03×10^{-8}	7.33×10^{-9}

Table 4.1-8. Annual average atmospheric diffusion factors (χ/Q') for the 200-East Area for an 89-m release based on 1983-1987 data.

	$\chi/Q' \text{ (s/m}^3\text{)}$									
	0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	6.28×10^{-8}	3.81×10^{-8}	3.21×10^{-8}	2.64×10^{-8}	2.20×10^{-8}	1.43×10^{-8}	7.37×10^{-9}	4.36×10^{-9}	3.06×10^{-9}	2.33×10^{-9}
NNE	2.83×10^{-8}	2.25×10^{-8}	1.90×10^{-8}	1.54×10^{-8}	1.27×10^{-8}	7.99×10^{-9}	3.96×10^{-9}	2.29×10^{-9}	1.59×10^{-9}	1.20×10^{-9}
NE	3.43×10^{-8}	2.54×10^{-8}	2.22×10^{-8}	1.82×10^{-8}	1.50×10^{-8}	9.55×10^{-9}	4.73×10^{-9}	2.73×10^{-9}	1.88×10^{-9}	1.42×10^{-9}
ENE	5.02×10^{-8}	3.14×10^{-8}	2.74×10^{-8}	2.27×10^{-8}	1.90×10^{-8}	1.23×10^{-8}	6.27×10^{-9}	3.68×10^{-9}	2.56×10^{-9}	1.95×10^{-9}
E	6.62×10^{-8}	6.81×10^{-8}	6.46×10^{-8}	5.53×10^{-8}	4.71×10^{-8}	3.14×10^{-8}	1.65×10^{-8}	9.83×10^{-9}	6.91×10^{-9}	5.28×10^{-9}
ESE	7.70×10^{-8}	9.62×10^{-8}	8.70×10^{-8}	7.21×10^{-8}	6.01×10^{-8}	3.87×10^{-8}	1.94×10^{-8}	1.13×10^{-8}	7.79×10^{-9}	5.89×10^{-9}
SE	1.06×10^{-7}	8.66×10^{-8}	7.05×10^{-8}	5.57×10^{-8}	4.52×10^{-8}	2.77×10^{-8}	1.32×10^{-8}	7.49×10^{-9}	5.10×10^{-9}	3.82×10^{-9}
SSE	9.92×10^{-8}	6.13×10^{-8}	4.80×10^{-8}	3.72×10^{-8}	2.96×10^{-8}	1.76×10^{-8}	8.16×10^{-9}	4.52×10^{-9}	3.05×10^{-9}	2.27×10^{-9}
S	1.59×10^{-7}	8.24×10^{-8}	6.09×10^{-8}	4.58×10^{-8}	3.58×10^{-8}	2.05×10^{-8}	9.08×10^{-9}	4.89×10^{-9}	3.25×10^{-9}	2.39×10^{-9}
SSW	1.05×10^{-7}	5.38×10^{-8}	3.91×10^{-8}	2.91×10^{-8}	2.26×10^{-8}	1.28×10^{-8}	5.57×10^{-9}	2.95×10^{-9}	1.94×10^{-9}	1.41×10^{-9}
SW	8.68×10^{-8}	5.30×10^{-8}	3.99×10^{-8}	3.00×10^{-8}	2.34×10^{-8}	1.33×10^{-8}	5.84×10^{-9}	3.13×10^{-9}	2.07×10^{-9}	1.52×10^{-9}
WSW	9.78×10^{-8}	5.21×10^{-8}	3.77×10^{-8}	2.79×10^{-8}	2.16×10^{-8}	1.22×10^{-8}	5.29×10^{-9}	2.83×10^{-9}	1.87×10^{-9}	1.37×10^{-9}
W	1.52×10^{-7}	7.83×10^{-8}	5.84×10^{-8}	4.42×10^{-8}	3.48×10^{-8}	2.02×10^{-8}	9.09×10^{-9}	4.96×10^{-9}	3.32×10^{-9}	2.46×10^{-9}
WNW	1.02×10^{-7}	5.49×10^{-8}	4.21×10^{-8}	3.25×10^{-8}	2.59×10^{-8}	1.55×10^{-8}	7.25×10^{-9}	4.06×10^{-9}	2.76×10^{-9}	2.07×10^{-9}
NW	8.34×10^{-8}	5.34×10^{-8}	4.23×10^{-8}	3.32×10^{-8}	2.68×10^{-8}	1.64×10^{-8}	7.89×10^{-9}	4.50×10^{-9}	3.09×10^{-9}	2.33×10^{-9}
NNW	5.23×10^{-8}	3.87×10^{-8}	3.22×10^{-8}	2.59×10^{-8}	2.13×10^{-8}	1.34×10^{-8}	6.72×10^{-9}	3.93×10^{-9}	2.74×10^{-9}	2.08×10^{-9}

Table 4.1-9. Annual average atmospheric diffusion factors (χ/Q') for the 200-East Area for a ground-level release based on 1983-1987 data.

	$\chi/Q' \text{ (s/m}^3\text{)}$									
	0.8 km	2.4 km	4.0 km	5.6 km	7.2 km	12 km	24 km	40 km	56 km	72 km
N	3.87×10^{-6}	6.08×10^{-7}	2.79×10^{-7}	1.70×10^{-7}	1.18×10^{-7}	5.72×10^{-8}	2.20×10^{-8}	1.10×10^{-8}	7.05×10^{-9}	5.06×10^{-9}
NNE	2.04×10^{-6}	3.21×10^{-7}	1.47×10^{-7}	8.93×10^{-8}	6.20×10^{-8}	3.00×10^{-8}	1.15×10^{-8}	5.75×10^{-9}	3.67×10^{-9}	2.63×10^{-9}
NE	2.43×10^{-6}	3.83×10^{-7}	1.75×10^{-7}	1.06×10^{-7}	7.39×10^{-8}	3.57×10^{-8}	1.37×10^{-8}	6.84×10^{-9}	4.35×10^{-9}	3.12×10^{-9}
ENE	3.30×10^{-6}	5.18×10^{-7}	2.37×10^{-7}	1.44×10^{-7}	1.00×10^{-7}	4.86×10^{-8}	1.86×10^{-8}	9.33×10^{-9}	5.95×10^{-9}	4.27×10^{-9}
E	8.99×10^{-6}	1.42×10^{-6}	6.54×10^{-7}	3.99×10^{-7}	2.77×10^{-7}	1.35×10^{-7}	5.19×10^{-8}	2.60×10^{-8}	1.66×10^{-8}	1.19×10^{-8}
ESE	9.59×10^{-6}	1.52×10^{-6}	6.94×10^{-7}	4.22×10^{-7}	2.93×10^{-7}	1.41×10^{-7}	5.40×10^{-8}	2.69×10^{-8}	1.71×10^{-8}	1.23×10^{-8}
SE	6.34×10^{-6}	9.93×10^{-7}	4.52×10^{-7}	2.73×10^{-7}	1.89×10^{-7}	9.08×10^{-8}	3.44×10^{-8}	1.71×10^{-8}	1.08×10^{-8}	7.74×10^{-9}
SSE	3.91×10^{-6}	6.07×10^{-7}	2.75×10^{-7}	1.66×10^{-7}	1.15×10^{-7}	5.50×10^{-8}	2.08×10^{-8}	1.03×10^{-8}	6.51×10^{-9}	4.64×10^{-9}
S	4.24×10^{-6}	6.51×10^{-7}	2.93×10^{-7}	1.76×10^{-7}	1.21×10^{-7}	5.75×10^{-8}	2.14×10^{-8}	1.05×10^{-8}	6.63×10^{-9}	4.71×10^{-9}
SSW	2.53×10^{-6}	3.87×10^{-7}	1.73×10^{-7}	1.04×10^{-7}	7.12×10^{-8}	3.36×10^{-8}	1.24×10^{-8}	6.06×10^{-9}	3.80×10^{-9}	2.69×10^{-9}
SW	2.98×10^{-6}	4.61×10^{-7}	2.08×10^{-7}	1.25×10^{-7}	8.57×10^{-8}	4.06×10^{-8}	1.51×10^{-8}	7.37×10^{-9}	4.63×10^{-9}	3.28×10^{-9}
WSW	2.60×10^{-6}	3.99×10^{-7}	1.79×10^{-7}	1.07×10^{-7}	7.39×10^{-8}	3.50×10^{-8}	1.30×10^{-8}	6.37×10^{-9}	4.01×10^{-9}	2.84×10^{-9}
W	4.45×10^{-6}	6.86×10^{-7}	3.10×10^{-7}	1.87×10^{-7}	1.29×10^{-7}	6.15×10^{-8}	2.31×10^{-8}	1.14×10^{-8}	7.22×10^{-9}	5.14×10^{-9}
WNW	3.65×10^{-6}	5.66×10^{-7}	2.57×10^{-7}	1.55×10^{-7}	1.07×10^{-7}	5.15×10^{-8}	1.95×10^{-8}	9.67×10^{-9}	6.14×10^{-9}	4.38×10^{-9}
NW	3.67×10^{-6}	5.72×10^{-7}	2.61×10^{-7}	1.58×10^{-7}	1.09×10^{-7}	5.26×10^{-8}	2.00×10^{-8}	9.97×10^{-9}	6.34×10^{-9}	4.53×10^{-9}
NNW	3.56×10^{-6}	5.60×10^{-7}	2.56×10^{-7}	1.56×10^{-7}	1.08×10^{-7}	5.24×10^{-8}	2.01×10^{-8}	1.00×10^{-8}	6.40×10^{-9}	4.59×10^{-9}

factor tables for both elevated and ground-level releases, respectively. An effective stack height of 89 m (292 ft) has been assumed for elevated releases in Table 4.1-8, based on an actual stack height of 60 m (197 ft) and a typical plume rise of 28 m (92 ft).

4.1.7 Air Quality

National ambient air quality standards (NAAQS) have been set by the U. S. Environmental Protection Agency (EPA), as mandated in the 1970 Clean Air Act and the Clean Air Act Amendments of 1990. Ambient air is that portion of the atmosphere, external to buildings, to which the general public has access. The standards define levels of air quality that are necessary, with an adequate margin of safety, to protect the public health (primary standards) and the public welfare (secondary standards). Standards exist for sulfur oxides (measured as sulfur dioxide), nitrogen dioxide, carbon monoxide, total suspended particulates (TSP), fine particulates (PM-10), lead, and ozone. The standards specify the maximum pollutant concentrations and frequencies of occurrence that are allowed for specific averaging periods (i.e., the concentration of carbon monoxide when averaged over 1 hour is allowed to exceed 40 mg/m³ only once per year). The averaging periods vary from 1 hour to 1 year, depending on the pollutant.

For clean areas, the EPA has established the Prevention of Significant Deterioration (PSD) program to protect existing ambient air quality while at the same time allowing a margin for future growth. The Hanford Site operates under a PSD permit issued by the EPA in 1980. The permit provides specific limits for emissions of oxides of nitrogen from the Plutonium Uranium Extraction (PUREX) and Uranium Oxide (UO₃) plants.

State and local governments have the authority to impose standards for ambient air quality that are stricter than the national standards. Washington State has established more stringent standards for sulfur dioxide and total suspended particulates. In addition, Washington State has established standards for volatile organic compounds (VOC), arsenic, fluoride, and other pollutants that are not covered by national standards. The state standards for carbon monoxide, nitrogen dioxide, ozone, fine particulates (PM₁₀), and lead are identical to the national standards. At the local level, the Tri-County Air Pollution Control Authority (renamed the Benton-Franklin Counties Clean Air Authority as of January 1994) has the authority to establish more stringent air standards, but has not done so. Table 4.1-10 summarizes the relevant air quality standards (federal and supplemental state standards).

Prevention of Significant Deterioration. Nitrogen oxide emissions from PUREX and the UO₃ plants are permitted under the PSD program. There were no PSD permit violations during 1992.

Major Stationary Emission Sources. Emission inventories for permitted pollution sources in Benton, Franklin, and Walla Walla counties are routinely compiled by the Tri-County Air Pollution Control Board (Benton-Franklin Counties Clean Air Authority). Table 4.1-11 lists the annual emission rates for stationary sources within the Hanford Site boundaries that have been reported to the Washington State Department of Ecology (Ecology) by the U. S. Department of Energy (DOE).

Table 4.1-10. National and Washington State ambient air quality standards^(a).

Pollutant	National Primary	National Secondary	Washington State
Total Suspended Particulates			
Annual geometric mean	NS ^(b)	NS	60 $\mu\text{g}/\text{m}^3$
24-h average	NS	NS	150 $\mu\text{g}/\text{m}^3$
PM-10 (fine particulates)			
Annual arithmetic mean	50 $\mu\text{g}/\text{m}^3$	50 $\mu\text{g}/\text{m}^3$	50 $\mu\text{g}/\text{m}^3$
24-h average	150 $\mu\text{g}/\text{m}^3$	150 $\mu\text{g}/\text{m}^3$	150 $\mu\text{g}/\text{m}^3$
Sulfur Dioxide			
Annual average	0.03 ppm	NS	0.02 ppm
24-h average	0.14 ppm	NS	0.10 ppm
3-h average	NS	0.50 ppm	NS
1-h average	NS	NS	0.40 ppm ^(c)
Carbon Monoxide			
8-h average	9 ppm	9 ppm	9 ppm
1-h average	35 ppm	35 ppm	35 ppm
Ozone			
1-h average ^(d)	0.12 ppm	0.12 ppm	0.12 ppm
Nitrogen Dioxide			
Annual average	0.05 ppm	0.05 ppm	0.05 ppm
Lead			
Quarterly average	1.5 $\mu\text{g}/\text{m}^3$	1.5 $\mu\text{g}/\text{m}^3$	1.5 $\mu\text{g}/\text{m}^3$

(a) Source: Ecology (1993). Annual standards are never to be exceeded; short-term standards are not to be exceeded more than once per year unless otherwise noted.

Abbreviations: ppm = parts per million; $\mu\text{g}/\text{m}^3$ = micrograms/cubic meter.

(b) NS = no standard.

(c) 0.25 ppm not to be exceeded more than twice in any 7 consecutive days.

(d) Not to be exceeded more than 1 day per calendar year.

Table 4.1-11. Emission rates for stationary emission sources within the Hanford Site for 1992^(a).

Source	Operation (hr/yr)	TSP (t/yr)	PM ₁₀ (t/yr)	SO ₂ (t/yr)	NO _x (t/yr)	VOC (t/yr)	CO (t/yr)
100-N Boiler	0	0	0	0	0	0	0
100-N Boiler	0	0	0	0	0	0	0
300-Area Temp. Boiler	6384	9	8	110	22	0	2
300-Area Boiler #3	0	0	0	0	0	0	0
300-Area Boiler #4	0	0	0	0	0	0	0
300-Area Boiler #5	0	0	0	0	0	0	0
300-Area Boiler #6	8760	4	3	48	10	0	1
300-Area Incinerator	0	0	0	0	0	0	0
200-E Boiler	8760	3	1	200	58	1	49
200-W Boiler	8760	4	1	260	75	1	62
1100-Area Boiler	0	0	0	0	0	0	0
1100-Area Boiler	0	0	0	0	0	0	0
200-E, 200-W Fugitive Coal	8760	107	54	0	0	0	0
200-E Fugitive Emissions	8760	1	0	0	0	0	0
200-E Area Backup Boiler	0	0	0	0	0	0	0
Res. Dis. Area Temp. Boiler	8760	9	8	120	24	0	2

(a) Source: Communication from Washington State Department of Ecology; 1992 emission rates. t/yr = tons per year; TSP = total suspended particulates; PM₁₀ = fine particulates; VOC = volatile organic compounds.

Onsite Monitoring. Monitoring of nitrogen oxides was discontinued after 1990 due in large part to the ceasing of operations at the PUREX plant. Monitoring of TSP was discontinued in early 1988 when the Basalt Waste Isolation Project, for which those measurements were required, was concluded.

Twenty-one air samples for PCB analysis were collected during 1992. All of the results were below the detection limit of ≤ 100 ng/sample component for each of the PCB mixtures. The corresponding air concentrations were < 0.29 ng/m³ (Woodruff et al. 1993). The EPA specifies a detection limit of 1 ng/m³, thus PCB's were well within the given air concentration limits.

There were eleven air samples collected for VOC analysis in 1992. These samples were analyzed for benzene, alkylbenzenes, halogenated alkanes, and alkenes. All of the

VOC concentrations measured were well within the maximum allowable concentrations of air contaminants (MACAC) as established in 29 CFR 1910, January 1989.

Offsite Monitoring. The only offsite monitoring in the vicinity of the Hanford Site in 1992, for PM_{10} , was conducted by Ecology (Ecology 1993). TSP monitoring at the Tri-Cities locations was discontinued in early 1989. Monitoring at the remaining two locations, Sunnyside and Wallula, was discontinued in May 1991.

PM_{10} was monitored at three locations: Columbia Center in Kennewick, Wallula, and the Walla Walla Fire Station (Table 4.1-12). During 1992, the 24-hour PM_{10} standard established by the state of Washington, $150 \mu g/m^3$, was exceeded twice at the Columbia Center monitoring location; the maximum 24-hour concentration at Columbia Center was $596 \mu g/m^3$; the other occurrence $> 150 \mu g/m^3$ was $183 \mu g/m^3$. None of the sites exceeded the annual primary standard, $50 \mu g/m^3$, during 1992.

Background Concentrations. During the past 10 years, carbon monoxide, sulfur dioxide, and nitrogen dioxide have been monitored periodically in communities and commercial areas southeast of Hanford. These urban measurements are typically used to estimate the maximum background pollutant concentrations for the Hanford Site because of the lack of specific onsite monitoring. Because these measurements were made in the vicinity of local sources of pollution, they will overestimate maximum background concentrations within the Hanford Site or at the Site boundaries.

Particulate concentrations can reach relatively high levels in eastern Washington State because of exceptional natural events (i.e., dust storms, volcanic eruptions, and large brushfires) that occur in the region. Washington State ambient air quality standards have not considered "rural fugitive dust" from exceptional natural events when estimating the maximum background concentrations of particulates in the area east of the Cascade

Table 4.1-12. Results of PM_{10} monitoring near the Hanford Site in 1992^(a).

<u>Location</u>	<u>Annual Arithmetic Mean ($\mu g/m^3$)</u>	<u>Max. Concentration ($\mu g/m^3$)</u>	<u>No. Occurrences > $150 \mu g/m^3$</u>
Kennewick, Columbia Center	26	596	2
Wallula	35	124	0
Walla Walla Fire Station	28	67	0

(a) Source: Ecology (1993).

Mountain crest. EPA has in the past exempted the rural fugitive dust component of background concentrations when considering permit applications and enforcement of air quality standards. However, EPA is now investigating the prospect of designating the Tri-County area (i.e. parts of Benton, Franklin, and Walla Walla counties) as a nonattainment area for fine particulate material (PM_{10}). Windblown dust has been identified as a particularly large problem in this area. A grant to Washington State University and the Agricultural Research Center has funded a study to ascertain the effects of this dust. The Department of Ecology has been working with the EPA and the local Air Quality District to control other sources of PM_{10} , thereby potentially delaying or preventing the need for the nonattainment designation. At this time, a final decision has not been made on this issue.

4.1.8 100 Areas

The surface wind pattern at the 100-N Area (see Figure 4.2-8 for location of 100 Areas) is greatly affected by the topographic influence of the Columbia River. The wind rose for station 13 (see Figure 4.1-2) shows a prevailing wind direction from the west-southwest (along the river) at the 10-m (33-ft) level. The 60-m (197-ft) tower at the 100-N Area provides additional data to define the wind at 60 m (197 ft), which is influenced less by surface features than the 10-m (33-ft) instrument.

Temperature measurements for this area were also initiated at the time the 60-m (197-ft) tower was erected. Temperature difference measurements between the 60-m (197-ft) and 10-m (33-ft) levels provide information for determining atmospheric stability, a parameter important to atmospheric dispersion calculations. The X/Q' values in Table 4.1-7 may be used.

4.1.9 300 Area

The wind rose for the 300 Area (Station 11) shows that the largest (and approximately the same) percentages of wind blow from the northwest/north-northwest and south-southwest/southwest directions (see Figure 4.1-2); however, winds from the southwest quadrant tend to be stronger.

Data collected by Washington Public Power Supply System for WNP-1 and data collected from the 10-m (33-ft) towers at the 300 and 400 Areas have differed significantly. Because these locations are relatively close together, Pacific Northwest Laboratory (PNL) constructed 60-m (197-ft) towers in the 300 and 400 Areas in 1986 to provide additional wind and temperature information to further define meteorological conditions in this area.

Nitrogen dioxide sampling and analysis were performed by the Hanford Environmental Health Foundation (HEHF).

4.2 Geology and Hydrology

4.2.1 Geology

4.2.1.1 Physiography

The Hanford Site lies within the Columbia Basin and Central Highlands subprovinces of the Columbia Intermontane Province (Figure 4.2-1). The Columbia Intermontane Province is the product of Miocene flood basalt volcanism and regional deformation that occurred over the past 17 million years. The Columbia Plateau is that portion of the Columbia Intermontane Province that is underlain by the Columbia River Basalt Group (Thornbury 1965).

The physiography of the Hanford Site is dominated by the low-relief plains of the Central Plains and anticlinal ridges of the Yakima Folds physiographic regions. The surface topography has been modified within the past several million years by several geomorphic processes: 1) Pleistocene cataclysmic flooding, 2) Holocene eolian activity, and 3) landsliding. Cataclysmic flooding occurred when ice dams in western Montana and northern Idaho were breached, allowing large volumes of water to spill across eastern and central Washington forming the channeled scablands and depositing sediments in the Pasco Basin. The last major flood occurred about 13,000 years ago, during the late Pleistocene Epoch. Anastomosing flood channels, giant current ripples, bergmounds, and giant flood bars are among the landforms created by the floods. The 200 Areas' waste management facilities are located on one prominent flood bar, the Cold Creek bar (Figure 4.2-2) (DOE 1988).

Since the end of the Pleistocene, winds have locally reworked the flood sediments, depositing dune sands in the lower elevations and loess (windblown silt) around the margins of the Pasco Basin. Many sand dunes have been stabilized by anchoring vegetation except where they have been reactivated by disturbing the vegetation.

Landslides occur along the north limbs of some Yakima Folds and along steep river embankments such as White Bluffs. Landslides on the Yakima Folds occur along sedimentary units intercalated with the basalt whereas active landslides at White Bluffs occur in suprabasalt sediments. The active landslides at White Bluffs are principally the result of irrigation activity east of the Columbia River.

4.2.1.2 Stratigraphy

The stratigraphy of the Hanford Site consists of Miocene-age and younger rocks. Older Cenozoic sedimentary and volcanoclastic rock underlie the Miocene and younger rocks but are not exposed at the surface. The Hanford Site stratigraphy is summarized in Figure 4.2-3 and described below. A more detailed discussion of the Hanford Site stratigraphy is given in DOE (1988).

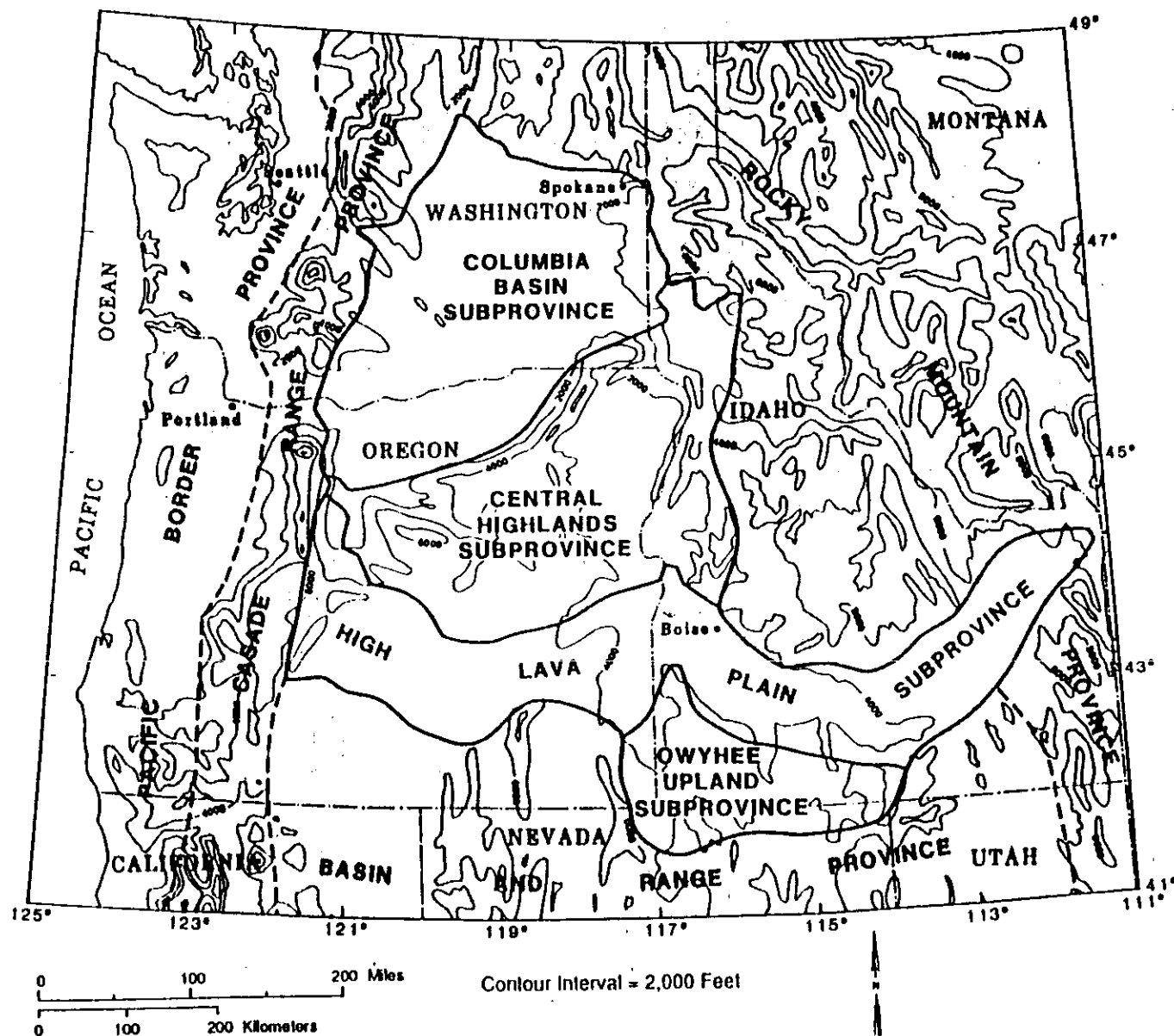


Figure 4.2-1. Physiographic provinces of the Pacific Northwest, with Columbia Intermontane Province shown in white.

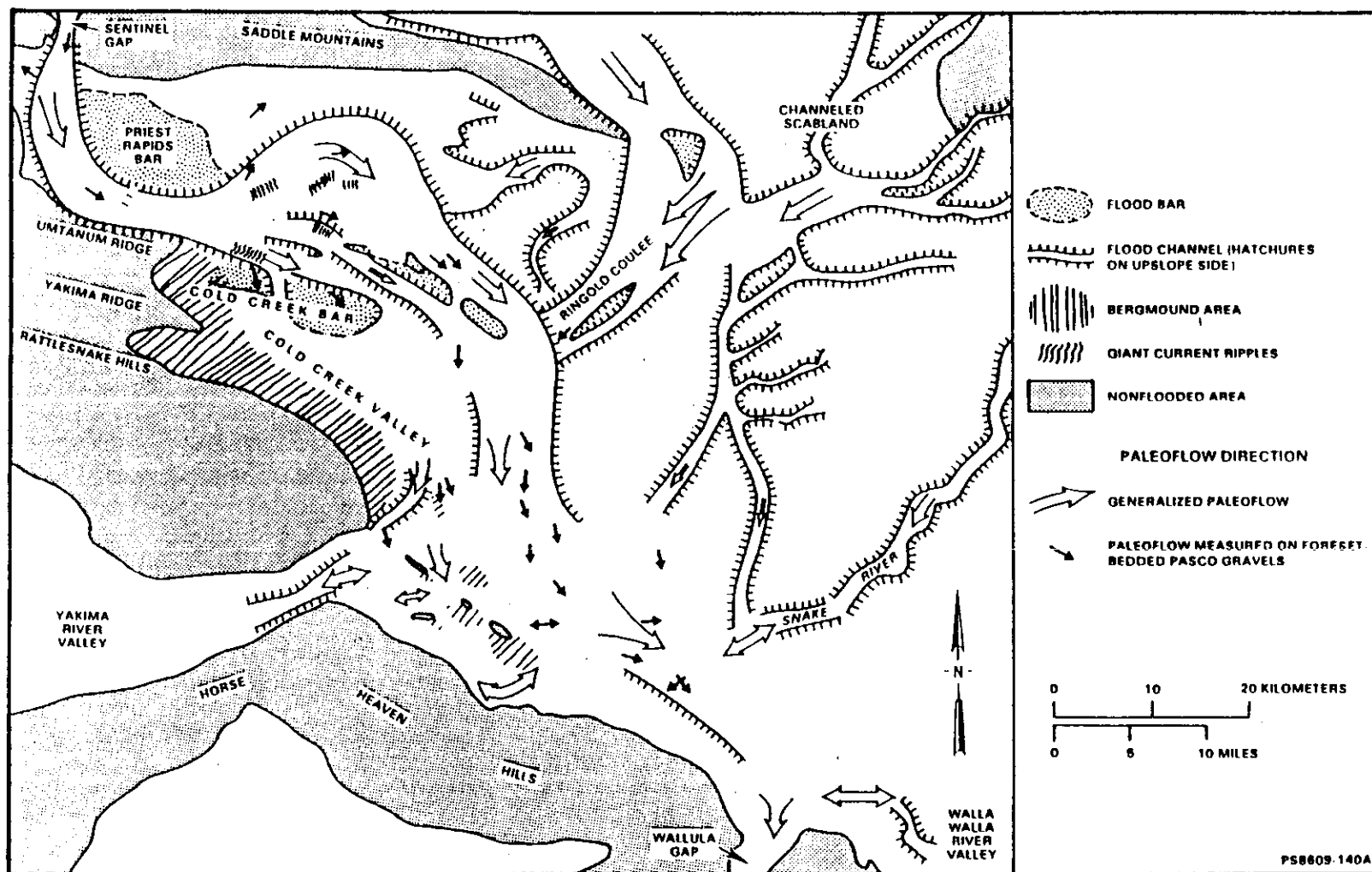


Figure 4.2-2. Paleoflow directions and landforms associated with cataclysmic flooding in the Central Columbia Plateau after 1988.

Period	Epoch	Group	Subgroup	Formation	K-Ar Age Years x 10 ⁶	Sediment Stratigraphy, Member, or Sequence	
						Loess	Sand Dunes
QUATERNARY	Pleistocene	Holocene		Hanford		Hanford Formation	
						Plio-pleistocene Unit	
TERTIARY	Pliocene		Ringold			Ringold Formation	Fanglomerate
	Miocene	Columbia River Basalt Group	Yakima Basalt Subgroup	Saddle Mountains Basalt	8.5	Ice Harbor Member	
						Levey Interbed	
					10.5	Elephant Mountain Member	
						Rattlesnake Ridge Interbed	
					12.0	Pomona Member	
						Selah Interbed	
						Esquatzel Member	
						Cold Creek Interbed	
					13.5	Asotin Member	
						Wilbur Creek Member	
						Umatilla Member	
						Mabton Interbed	
			Wanapum Basalt		14.5	Priest Rapids Member	
						Quincy Interbed	
						Roza Member	
						Squaw Creek Interbed	
						Frenchman Springs Member	
						Vantage Interbed	
			Grande Ronde Basalt		15.6	Sentinel Bluffs Sequence	
					16.5	Schwana Sequence	

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Figure 4.2-3. Stratigraphic column for the Pasco Basin.

Columbia River Basalt Group. The Columbia River Basalt Group (Figure 4.2-3) comprises an assemblage of tholeiitic, continental flood basalts of Miocene age. These flows cover an area of more than 163,170 km² (63,000 mi²) in Washington, Oregon, and Idaho and have an estimated volume of about 174,000 km³ (67,200 m³) (Tolan et al. 1987). Isotopic age determinations suggest flows of the Columbia River Basalt Group were erupted during a period from approximately 17 to 6 million years ago, with more than 98% by volume being erupted in a 2.5 million-year period (17 to 14.5 million years ago).

Columbia River basalt flows were erupted from north-northwest-trending fissures or linear vent systems in north-central and northeastern Oregon, eastern Washington, and western Idaho (Swanson et al. 1979; Waters 1961). The Columbia River Basalt Group is formally divided into five formations, from oldest to youngest: Imnaha Basalt, Picture Gorge Basalt, Grande Ronde Basalt, Wanapum Basalt, and Saddle Mountains Basalt. Of these, only the Grande Ronde, Wanapum, and Saddle Mountains Basalts are known to be present in the Pasco Basin. The Saddle Mountains Basalt forms the uppermost basalt unit in the Pasco Basin except along some of the bounding ridges where Wanapum and Grande Ronde Basalt flows are exposed.

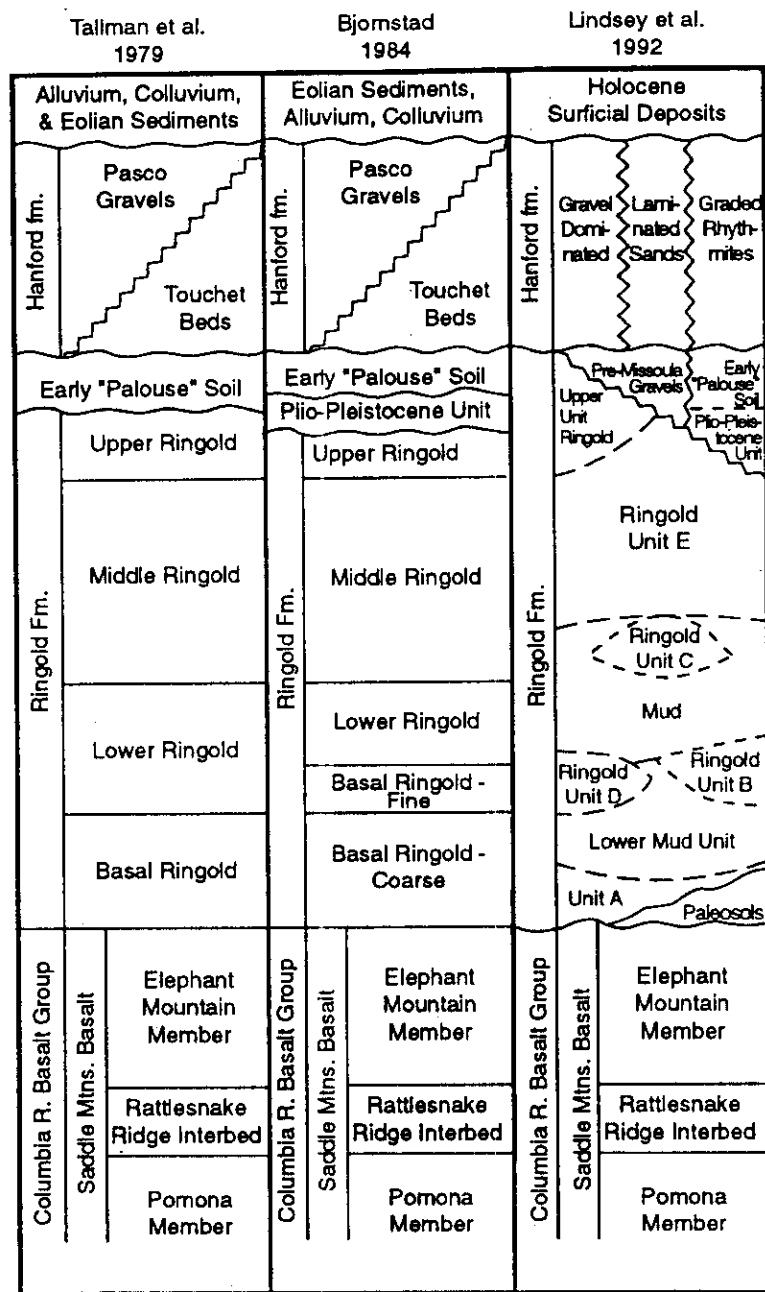
Ellensburg Formation. The Ellensburg Formation (Figure 4.2-3) includes epiclastic and volcanoclastic sedimentary rocks interbedded with the Columbia River Basalt Group in the central and western part of the Columbia Plateau (Schmincke 1964; Swanson et al. 1979; Smith 1988). The age of the Ellensburg Formation is principally Miocene, although locally it may be equivalent to early Pliocene. The thickest accumulations of the Ellensburg Formation lie along the western margin of the Columbia Plateau where Cascade Range volcanic and volcanoclastic materials interfinger with the Columbia River Basalt Group. Within the Pasco Basin, individual interbeds have been named (i.e., Mabton, Selah, Cold Creek) and these deposits are found primarily in the Wanapum and Saddle Mountains Basalts. The lateral extent and thickness of interbedded sediments generally increase upward in the section (Reidel and Fecht 1981). Two major facies, volcanoclastic and fluvial, are present either as distinct or mixed deposits.

Suprabasalt Sediments. The suprabasalt sediments within and adjacent to the Hanford Site (Figure 4.2-3) are dominated by the fluvial-lacustrine Ringold Formation and glaciofluvial Hanford formation, with minor eolian and colluvium deposits (Tallman et al. 1981; DOE 1988; Baker et al. 1991).

Ringold Formation. Late Miocene to Pliocene deposits, younger than the Columbia River Basalt Group, are represented by the Ringold Formation within the Pasco Basin (Grolier and Bingham 1978; Gustafson 1973; Newcomb et al. 1972; Rigby and Othberg 1979). The fluvial-lacustrine Ringold Formation was deposited in generally east-west trending valleys by the ancestral Columbia River and its tributaries in response to development of the Yakima Fold Belt. While exposures of the Ringold Formation are limited to White Bluffs within the central Pasco Basin and to Smyrna and Taunton Benches north of the Pasco Basin, extensive data on the Ringold Formation are available from boreholes.

Fluvial deposits of the Ringold Formation can be broken into three facies associations based on proximity to the ancestral Columbia and/or Snake River channels and the related paleogeography during Ringold time. Gravel and associated sand and silt represent a migrating channel deposit of the major, thoroughgoing river systems and are generally confined to the central portion of the Pasco Basin. Overbank sand, silt, and clay reflect occasional deposition and flooding beyond the influence of the main river channels, and are generally found along the margins of the Pasco Basin. Fanglomerates, composed of mostly angular basaltic debris derived from side-stream alluvium shed off bedrock ridges, occur locally around the extreme margins of the basin. Over time, the main river channels moved back and forth across the basin, causing a shift in location of the various facies. Periodically, the river channels were blocked, causing lakes to develop in which laminated mud with minor sand was deposited.

In Tallman et al. (1979), the Ringold Formation was divided into four lithofacies units. In ascending order, they are the coarse-grained basal Ringold, the fine-grained lower Ringold, the coarse-grained middle Ringold, and the fine-grained upper Ringold units (Figure 4.2-4). Bjornstad (1984) further subdivided the basal Ringold unit. A new approach is being developed to reevaluate the Ringold stratigraphy using facies associations (Lindsey and Gaylord 1989; Lindsey 1991a). Figure 4.2-4 shows the relationships between these different stratigraphic nomenclatures. The stratigraphic divisions of the Ringold Formation as presented in Lindsey et al. (1992) will be used in this report. Lowermost in the Ringold is Unit A, a fluvial sand and gravel unit that occurs in the central portion of the Pasco Basin, pinching out toward the margins of the basin and onto the anticlines. Unit A correlates to the coarse-grained portion of the Basal Ringold Member. Overlying this coarse-grained unit is the relatively extensive Lower Mud Sequence, consisting of overbank and lacustrine deposits of mud and occasionally sand. The Lower Mud Sequence is found throughout much of the Pasco Basin, pinching out on the southern flank of the Umtanum Ridge-Gable Mountain anticline and near the margins of the basin. It correlates to the fine-grained portion of the Basal Ringold Member and the Lower Ringold Member. Overlying the Lower Mud Unit is a complex series of sedimentary units deposited by ancestral Columbia River as it shifted back and forth across the Pasco Basin over time. Main-channel facies gravel and sand units overlie the Lower Mud Unit over much of the Pasco Basin. Where these coarse-grained units are overlain by another mud unit, the gravelly sediments are designated Unit B in the eastern part of the basin, or Unit D in the western part. In the 200 West Area and vicinity, there is only one thick sequence of fluvial gravel and sand, part of which may include sediments correlative to Unit D. In some areas north of Gable Mountain and in the eastern part of the Pasco Basin, the unnamed mud is overlain by another series of coarse-grained fluvial sediments, designated Unit C, and another unnamed mud unit. These unnamed mud units are thickest in the northern and northeastern parts of the Hanford Site, where they form extensive series of overbank/paleosol sequences.



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Figure 4.2-4. Stratigraphic column for the Hanford Site showing correlations among various authors.

Ringold Unit E correlates to the Middle Ringold Member, and may lie directly upon any of the above units. If the underlying unit is a fluvial gravel facies, it is virtually indistinguishable from sediments in Unit E and the entire sequence is generally called Unit E. It is present throughout most of the Hanford Site, with the exception of the northern and northeastern portions, where the Ringold contains virtually no main-channel deposits. Overlying Unit E is the Upper Ringold Unit, which directly corresponds to previous nomenclature and stratigraphy. This unit consists of overbank/paleosol deposits found over much of the Hanford Site, but has been eroded from the 200 East and 300 areas. Most of White Bluffs on the east side of the Columbia River consists of Upper Ringold sediments.

Deposition of the Ringold Formation was followed by a period of regional incision in the late Pliocene to early Pleistocene. Within the Pasco Basin, this is reflected by the abrupt termination and eroded nature of the top of the Ringold Formation (Brown 1960; Bjornstad 1985; Newcomb et al. 1972). Following incision, a well-developed soil formed on top of the eroded surface. The exact timing and duration of incision are unknown; however, it probably occurred between 1 and 3.4 million years ago.

Plio-Pleistocene Unit. A locally derived unit consisting of a sidestream alluvium and/or pedogenic calcrete occurs at the unconformity between the Ringold Formation and the Hanford formation (Bjornstad 1984, 1985). The sidestream alluvial facies is derived from Cold Creek and its tributaries and is characterized by relatively thick zones of unweathered basalt clasts along with pedogenically altered loess or colluvium. The calcrete is relatively thick and impermeable in areas of the western Pasco Basin, often forming an aquitard to downward migration of water in the vadose zone where artificial recharge is occurring.

Early "Palouse" Soil. Overlying the Plio-Pleistocene unit in the Cold Creek syncline area is a fine-grained sand to silt. It is believed to be mainly of eolian origin, derived from either an older reworked Plio-Pleistocene unit or upper Ringold. The early Palouse soil differs from the overlying slackwater flood deposits by a greater calcium-carbonate content, massive structure in core samples, and a high natural gamma response in geophysical logs.

Quaternary Deposits. Aggradation of sediments resumed during the Quaternary following the period of late-Pliocene to early-Pleistocene incision. In the central Columbia Plateau, the Quaternary record is dominated by proglacial cataclysmic flood deposits with lesser amounts of fluvial and eolian deposits lying below, between, and above flood deposits.

Sand and gravel river sediments, referred to informally as the pre-Missoula gravels (PSPL 1982), were deposited after incision of the Ringold and prior to deposition of the cataclysmic flood deposits. The pre-Missoula gravels are very similar to the Ringold Formation main-channel gravel facies, consisting of dominantly non-basaltic clasts. These sediments appear to occur in a swath that runs from the old Hanford townsite on the eastern side of the Hanford Site across the site toward Horn Rapids on the Yakima River.

Cataclysmic floods inundated the Pasco Basin a number of times during the Pleistocene, beginning as early as 1 million years ago (Bjornstad and Fecht 1989); the last major flood sequence is dated at about 13,000 yr ago by the presence of Mount St. Helens

"S" tephra (Mullineaux et al. 1978) interbedded with the flood deposits. The number and timing of cataclysmic floods continues to be debated. Baker et al. (1991) document as many as 10 flood events during the last ice age. The largest and most frequent floods came from glacial Lake Missoula in northwestern Montana; however, smaller floods may have escaped downvalley from glacial Lakes Clark and Columbia along the northern margin of the Columbia Plateau (Waitt 1980), or down the Snake River from glacial Lake Bonneville (Malde 1968). The flood deposits, informally called the Hanford formation, blanket low-lying areas over most of the central Pasco Basin.

Cataclysmic floodwaters entering the Pasco Basin quickly became impounded behind Wallula Gap, which was too restrictive for the volume of water involved. Floodwaters formed temporary lakes with a shoreline up to 381.25 m (1250 ft) in elevation, which lasted only a few weeks or less (Baker 1978). Two end-member types of flood deposits are normally observed: a sand-and-gravel, main-channel facies, and a mud-and-sand, slackwater facies. Within the Pasco Basin, these are referred to as the Pasco Gravels and slackwater deposits of the Hanford formation (Myers et al. 1979). Sediments with intermediate grain sizes (e.g., sand) are also present in areas throughout the Pasco Basin, particularly on the south, relatively protected half of Cold Creek bar.

Clastic dikes are commonly associated with, but not restricted to, cataclysmic flood deposits on the Columbia Plateau. While there is general agreement that clastic dikes formed during cataclysmic flooding, a primary mechanism to satisfactorily explain the formation of all dikes has not been identified (WPPSS 1981). Among the more probable explanations are fracturing initiated by hydrostatic loading and hydraulic injection associated with receding floodwaters. These dikes may provide vertical pathways for downward migration of water through the vadose zone.

Alluvium is present, not only as a surficial deposit along major river and stream courses (Figure 4.2-5), but also in the subsurface, where it is found underlying, and interbedded with, proglacial flood deposits. Two types of alluvium are recognized in the Pasco Basin: quartzitic mainstream and basalt-rich sidestream alluvium. Colluvium (talus and slopewash) is a common Holocene deposit in moderate-to-high relief areas. Colluvium, like the dune sand that is found locally in the Pasco Basin, is not commonly preserved in the stratigraphic record. Varying thicknesses of loess or sand mantle much of the Columbia Plateau. Active and stabilized sand dunes are widespread over the Pasco Basin (Figure 4.2-5).

Landslide deposits in the Pasco Basin are of variable age and genesis. Most occur within the basalt outcrops along the ridges, such as on the north side of Rattlesnake Mountain, or steep river embankments such as White Bluffs, where the upper Ringold unit outcrops in the Pasco Basin (Figure 4.2-5).

4.2.1.3 Structural Geology of the Region

The Hanford Site is located near the junction of the Yakima Fold Belt and the Palouse structural subprovinces (DOE 1988). These structural subprovinces are defined on the

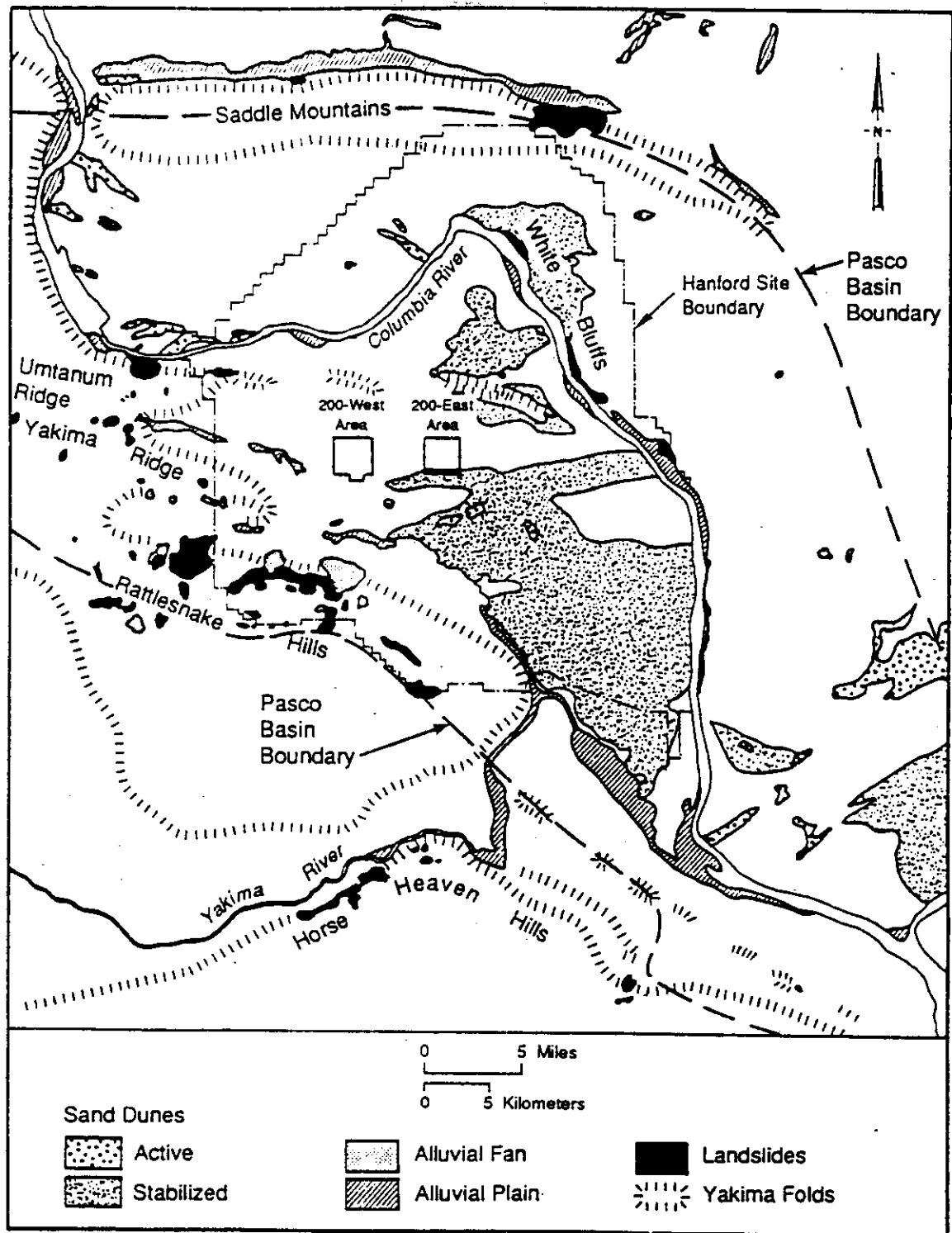


Figure 4.2-5. Map showing location of surficial features.

basis of their structural fabric, unlike the physiographic provinces that are defined on the basis of landforms. The Palouse subprovince is primarily a regional paleoslope that dips gently toward the central Columbia Plateau and exhibits only relatively mild structural deformation. The Palouse Slope is underlain by a wedge of Columbia River basalt that thins gradually toward the east and north and laps onto the adjacent highlands.

The principal characteristics of the Yakima Fold Belt are a series of segmented, narrow, asymmetric anticlines that have wavelengths between 5 and 31 km (3 and 19 mi) and amplitudes commonly < 1 km (0.6 mi) (Reidel et al. 1989). These anticlinal ridges are separated by broad synclines or basins that, in many cases, contain thick accumulations of Neogene- to Quaternary-age sediments. The deformation of the Yakima Folds occurred under north-south compression and was probably contemporaneous with the eruption of the basalt flows (Reidel 1984). The fold belt was growing during the eruption of the Columbia River Basalt Group and continued to grow into the Pleistocene and probably into the present.

Thrust or high-angle reverse faults with fault planes that strike parallel or subparallel to the axial trends are principally found along the limbs of the anticlines (Bentley et al. 1980; Hagood 1985; Reidel 1984; Swanson et al. 1979, 1981). The amount of vertical stratigraphic offset associated with these faults varies but commonly exceeds hundreds of meters.

The Saddle Mountains uplift is a segmented anticlinal ridge extending from near Ellensburg to the western edge of the Palouse Slope. This ridge forms the northern boundary of the Pasco Basin and the Wahluke syncline (Figure 4.2-6). It is generally steepest on the north, with a gently dipping southern limb. A major thrust or high-angle reverse fault occurs on the north side (Reidel 1984).

The Umtanum Ridge-Gable Mountain uplift is a segmented, asymmetrical anticlinal ridge extending 137 km (85 mi) in an east-west direction and passing north of the 200 Areas (Figure 4.2-6), forming the northern boundary of the Cold Creek syncline and the southern boundary of the Wahluke syncline. Three of this structure's segments are located on or adjacent to the Hanford Site. From the west, Umtanum Ridge plunges eastward towards the basin and merges with the Gable Mountain-Gable Butte segment. The latter segment then merges with the Southeast Anticline, which trends southeast before dying out near the Columbia River eastern boundary of the Gable Mountain-Gable Butte segment.

There is a major thrust to high-angle reverse fault on the north side (PSPL 1982) that dies out as it plunges eastward past the Gable Mountain-Gable Butte segment. Gable Mountain and Gable Butte are two topographically isolated, anticlinal ridges composed of a series of northwest-trending, doubly plunging, echelon anticlines, synclines, and associated faults. The potential for present-day faulting has been identified on Gable Mountain (PSPL 1982).

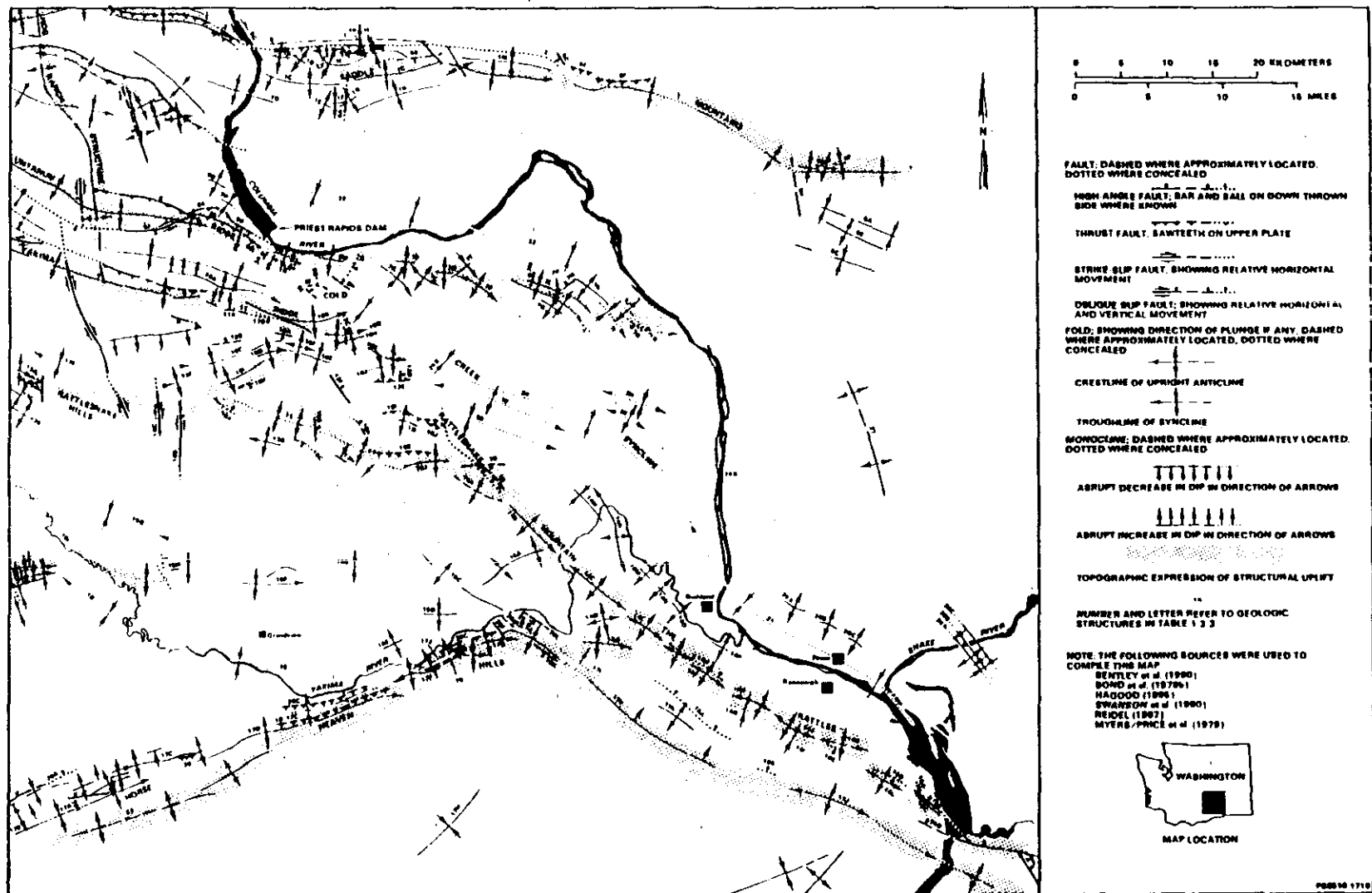


Figure 4.2-6. Location of structural features (from DOE 1988).

The Yakima Ridge uplift extends from west of Yakima to the center of the Pasco Basin, where it forms the southern boundary of the Cold Creek syncline (DOE 1988) (Figure 4.2-6). The Yakima Ridge anticline plunges eastward into the Pasco Basin, where it continues on a southeastern trend mostly buried beneath sediments. A thrust to high-angle reverse fault is thought to be present on the north side of the anticline, dying out as the fold extends to the east.

Rattlesnake Mountain is an asymmetrical anticline with a steeply dipping and faulted northern unit that forms the southern boundary of the Pasco Basin (Figure 4.2-6). It extends from the structurally complex Snively Basin area southeast to the Yakima River, where the uplift continues as a series of doubly plunging anticlines (Fecht et al. 1984). At Snively Basin the Rattlesnake Mountain structure intersects the Rattlesnake Hills anticline, which extends beyond Yakima and has an east-west trend.

The Cold Creek syncline (Figure 4.2-6) lies between the Umtanum Ridge-Gable Mountain uplift and the Yakima Ridge uplift. The Cold Creek syncline is an asymmetric and relatively flat-bottomed structure (DOE 1988). The Wahluke syncline lies between Saddle Mountains and the Umtanum Ridge-Gable Mountain uplifts. It, too, is asymmetric and relatively flat-bottomed, and is broader than the Cold Creek syncline (Myers et al. 1979).

The Cold Creek Fault (previously called the Yakima Barricade geophysical anomaly) (Figure 4.2-6) occurs on the west end of the Cold Creek syncline and coincides with a west-to-east change in hydraulic gradient. The data suggest that this feature is a high-angle fault that has faulted the basalts and, at least, the older Ringold units (Johnson et al. 1993). This fault apparently has not affected younger Ringold units or the Hanford formation.

Another fault, informally called the May Junction fault here, is located nearly 3 miles east of the 200-East Area. Like the Cold Creek fault, this fault is thought to be a high-angle fault that has offset the basalts and the older Ringold units. It does not appear to have affected the younger Ringold units or the Hanford formation.

4.2.1.4 Soils

Hajek (1966) lists and describes 15 different soil types on the Hanford Site, varying from sand to silty and sandy loam. These are shown in Figure 4.2-7 and briefly described in Table 4.2-1. Various classifications, including land use, are also given in Hajek (1966).

4.2.1.5 Seismicity

The historic record of earthquakes in the Pacific Northwest dates from about 1840. The early part of this record is based on newspaper reports of structural damage and human perception of the shaking, as classified by the Modified Mercalli Intensity (MMI) scale, and is probably incomplete because the region was sparsely populated. Seismograph networks did not start providing earthquake locations and magnitudes of earthquakes in the Pacific Northwest until about 1960. A comprehensive network of

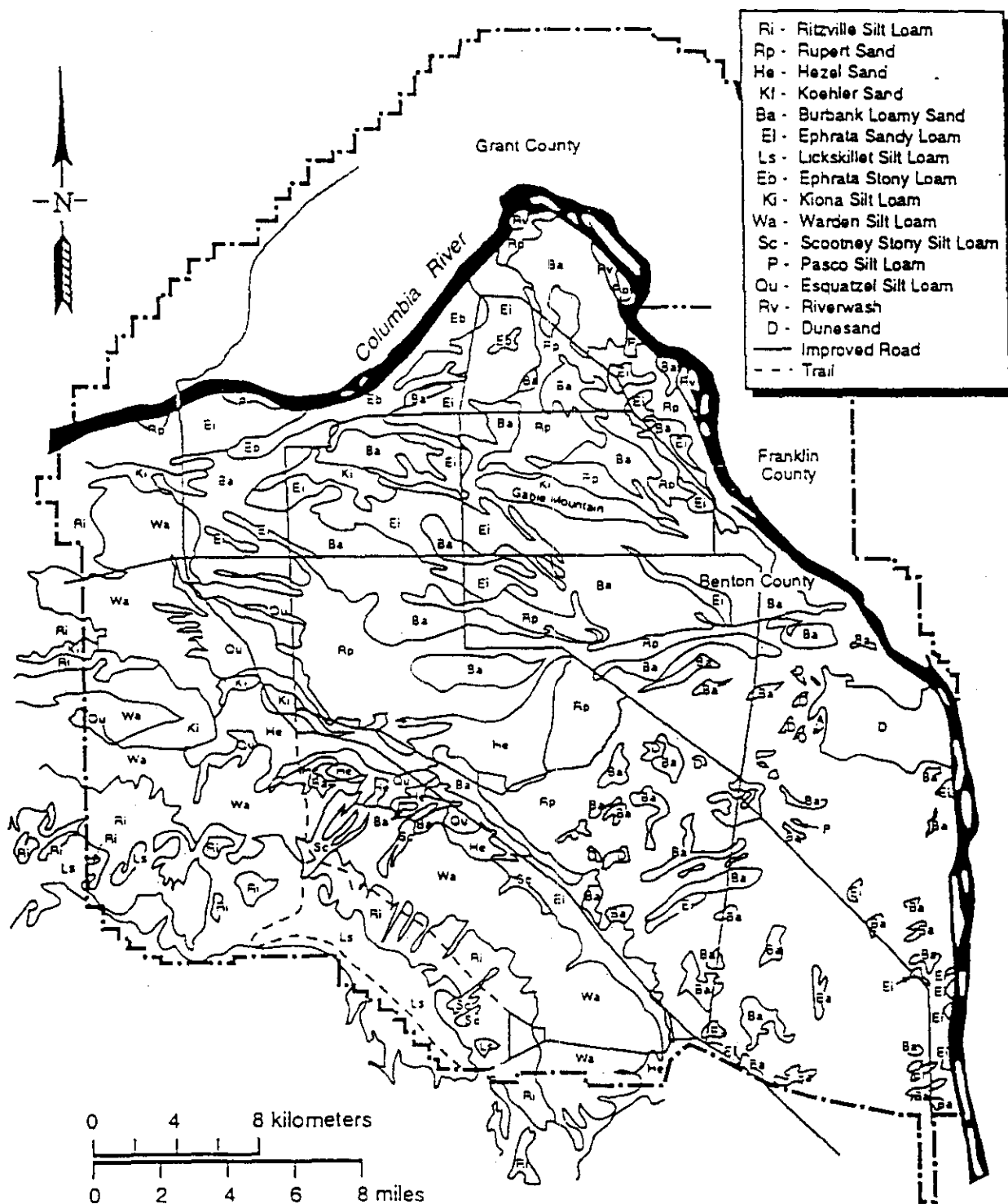


Figure 4.2-7. Soil map of the Hanford Site.

Table 4.2-1. Soil types on the Hanford Site (after Hajek 1966).

Name (symbol)	Description
Ritzville Silt Loam (Ri)	Dark-colored silt loam soils midway up the slopes of the Rattlesnake Hills. Developed under bunch grass from silty wind-laid deposits mixed with small amounts of volcanic ash. Characteristically > 150 cm (60 in.) deep, but bedrock may occur at < 150 cm (60 in.) but > 75 cm (30 in.).
Quincy Sand (Rp)	One of the most extensive soils on the Hanford Site. Brown-to-grayish-brown coarse sand grading to dark grayish-brown at 90 cm (35 in.). Developed under grass, sagebrush, and hopsage in coarse sandy alluvial deposits that were mantled by wind-blown sand. Hummocky terraces and dunelike ridges.
Hazel Sand (He)	Similar to Rupert sands; however, a laminated grayish-brown strongly calcareous silt loam subsoil is usually encountered within 100 cm (39 in.) of the surface. Surface soil is very dark brown and was formed in wind-blown sands that mantled lake-laid sediments.
Koehler Sand (Kf)	Similar to other sandy soils on the Hanford Site. Developed in a wind-blown sand mantle. Differs from other sands in that the sand mantles a lime-silica cemented layer "Hardpan." Very dark grayish-brown surface layer is somewhat darker than Rupert. Calcareous subsoil is usually dark grayish-brown at about 45 cm (18 in.).
Burbank Loamy Sand (Ba)	Dark-colored, coarse-textured soil underlain by gravel. Surface soil is usually about 40 cm (16 in.) thick but can be 75 cm (30 in.) thick. Gravel content of subsoil ranges from 20% to 80%.
Kiona Silt Loam (Ki)	Occupies steep slopes and ridges. Surface soil is very dark grayish-brown and about 10 cm (4 in.) thick. Dark-brown subsoil contains basalt fragments 30 cm (12 in.) and larger in diameter. Many basalt fragments found in surface layer. Basalt rock outcrops present. A shallow stony soil normally occurring in association with Ritzville and Warden soils.
Warden Silt Loam (Wa)	Dark grayish-brown soil with a surface layer usually 23 cm (9 in.) thick. Silt loam subsoil becomes strongly calcareous at about 50 cm (20 in.) and becomes lighter colored. Granitic boulders are found in many areas. Usually > 150 cm (60 in.) deep.
Ephrata Sandy Loam (EI)	Surface is dark colored and subsoil is dark grayish-brown medium-textured soil underlain by gravelly material, which may continue for many feet. Level topography.
Ephrata Stony Loam (Eb)	Similar to Ephrata sandy loam. Differs in that many large hummocky ridges are presently made up of debris released from melting glaciers. Areas between hummocks contain many boulders several feet in diameter.

Table 4.2-1. (contd)

Name (symbol)	Description
Scotney Stony Silt	Developed along the north slope of Rattlesnake Loam (Sc) Hills; usually confined to floors of narrow draws or small fan-shaped areas where draws open onto plains. Severely eroded with numerous basaltic boulders and fragments exposed. Surface soil is usually dark grayish-brown grading to grayish-brown in the subsoil.
Pasco Silt Loam (P)	Poorly drained very dark grayish-brown soil formed in recent alluvial material. Subsoil is variable, consisting of stratified layers. Only small areas found on Hanford Site, located in low areas adjacent to the Columbia River.
Esquatzel Silt Loam (Qu)	Deep dark-brown soil formed in recent alluvium derived from loess and lake sediments. Subsoil grades to dark grayish-brown in many areas, but color and texture of the subsoil are variable because of the stratified nature of the alluvial deposits.
Riverwash (Rv)	Wet, periodically flooded areas of sand, gravel, and boulder deposits that make up overflowed islands in the Columbia River and adjacent land.
Dune Sand (D)	Miscellaneous land type that consists of hills or ridges of sand-sized particles drifted and piled up by wind and are either actively shifted or so recently fixed or stabilized that no soil horizons have developed.
Lickskillet Silt Loam (Ls)	Occupies ridge slopes of Rattlesnake Hills and slopes > 765 m (2509 ft) elevation. Similar to Kiona series except surface soils are darker. Shallow over basalt bedrock, with numerous basalt fragments throughout the profile, suggests a location within a broad region between Lake Chelan, Washington, and the British Columbia border.

seismic stations that provides accurate locating information for most earthquakes of magnitude > 2.5 was installed in eastern Washington in 1969. DOE (1988) provides a summary of the seismicity of the Pacific Northwest, a detailed review of the seismicity in the Columbia Plateau region and the Hanford Site, and a description of the seismic networks used to collect the data.

Large earthquakes (Richter magnitude > 7) in the Pacific Northwest have occurred in the vicinity of Puget Sound, Washington and near the Rocky Mountains in eastern Idaho and western Montana. One of these events occurred near Vancouver Island in 1946, and produced a maximum MMI of VIII and a Richter magnitude of 7.3. Another large event occurred near Olympia, Washington in 1949 at a maximum intensity of MMI VIII and a Richter magnitude of 7.1. The two largest events near the Rocky Mountains were the

1959 Hebgen Lake earthquake in western Montana, which had a Richter magnitude of 7.5 and a MMI X, and the 1983 Borah Peak earthquake in eastern Idaho, which had a Richter magnitude of 7.3 and a MMI IX.

A large earthquake of uncertain location occurred in north-central Washington in 1872. This event had an estimated maximum MMI ranging from VIII to IX and an estimated magnitude of approximately 7. The distribution of intensities suggests a location within a broad region between Lake Chelan, Washington and the British Columbia border.

Seismicity of the Columbia Plateau, as determined by the rate of earthquakes per area and the historical magnitude of these events, is relatively low when compared with other regions of the Pacific Northwest, the Puget Sound area, and western Montana/eastern Idaho. Figure 4.2-8 shows the locations of all earthquakes that occurred in the Columbia Plateau before 1969 with MMI of \geq IV and at magnitude \geq 3, and Figure 4.2-9 shows the locations of all earthquakes that occurred from 1969 to 1986 at magnitudes \geq 3. The largest known earthquake in the Columbia Plateau occurred in 1936 around Milton-Freewater, Oregon. This earthquake had a magnitude of 5.75 and a maximum MMI of VII, and was followed by a number of aftershocks that indicate a northeast-trending fault plane. Other earthquakes with magnitudes \geq 5 and/or intensities of VI are located along the boundaries of the Columbia Plateau in a cluster near Lake Chelan extending into the northern Cascade Range, in northern Idaho and Washington, and along the boundary between the western Columbia Plateau and the Cascade Range. Three MMI VI earthquakes have occurred within the Columbia Plateau, including one event in the Milton-Freewater region in 1921, one near Yakima, Washington in 1892, and one near Umatilla, Oregon in 1893.

In the central portion of the Columbia Plateau, the largest earthquakes near the Hanford Site are two earthquakes that occurred in 1918 and 1973. These two events were magnitude 4.4 and intensity V, and were located north of the Hanford Site. Earthquakes often occur in spatial and temporal clusters in the central Columbia Plateau, and are termed "earthquake swarms." The region north and east of the Hanford Site is a region of concentrated earthquake swarm activity, but earthquake swarms have also occurred in several locations within the Hanford Site.

Earthquakes in a swarm tend to gradually increase and decay with frequency of events, and there is usually no one outstanding large event within the sequence. These earthquake swarms occur at shallow depths, with 75% of the events located at depths < 4 km (2.5 mi). Each earthquake swarm typically lasts several weeks to months, consists of several to 100 or more earthquakes, and is clustered in an area 5 to 10 km (3 to 6 mi) in lateral dimension. Often, the longest dimension of the swarm area is elongated in an east-west direction. However, detailed locations of swarm earthquakes indicate that the events occur on fault planes of variable orientation, and not on a single, thoroughgoing fault plane.

Earthquakes in the central Columbia Plateau also occur to depths of about 30 km (18 mi). These deeper earthquakes are less clustered and occur more often as single,

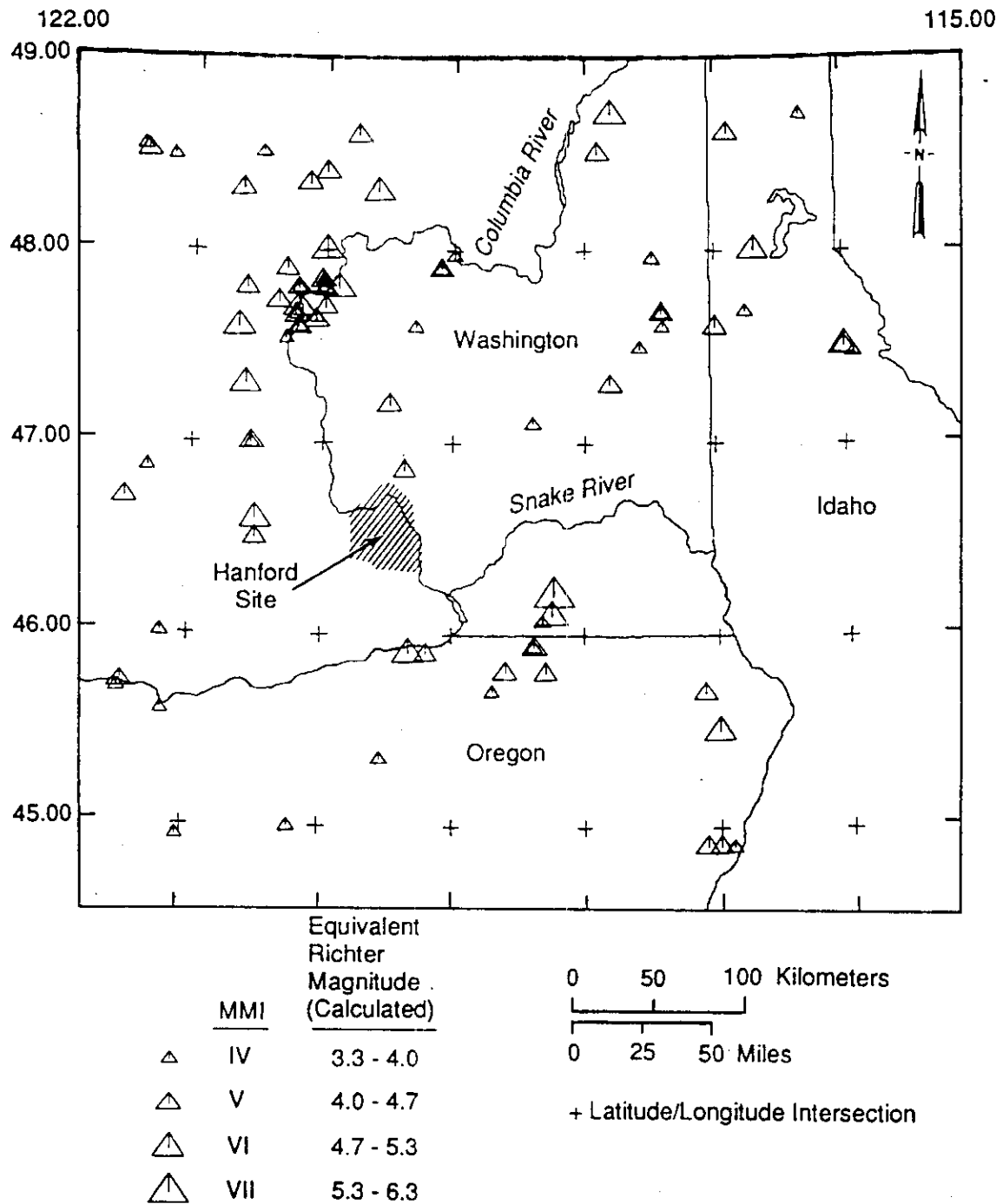


Figure 4.2-8. Historical seismicity of the Columbia Plateau and surrounding areas. All earthquakes between 1850 and 1969 with a Modified Mercalli Intensity of $\geq IV$ and a magnitude ≥ 3 are shown (Rohay 1989).

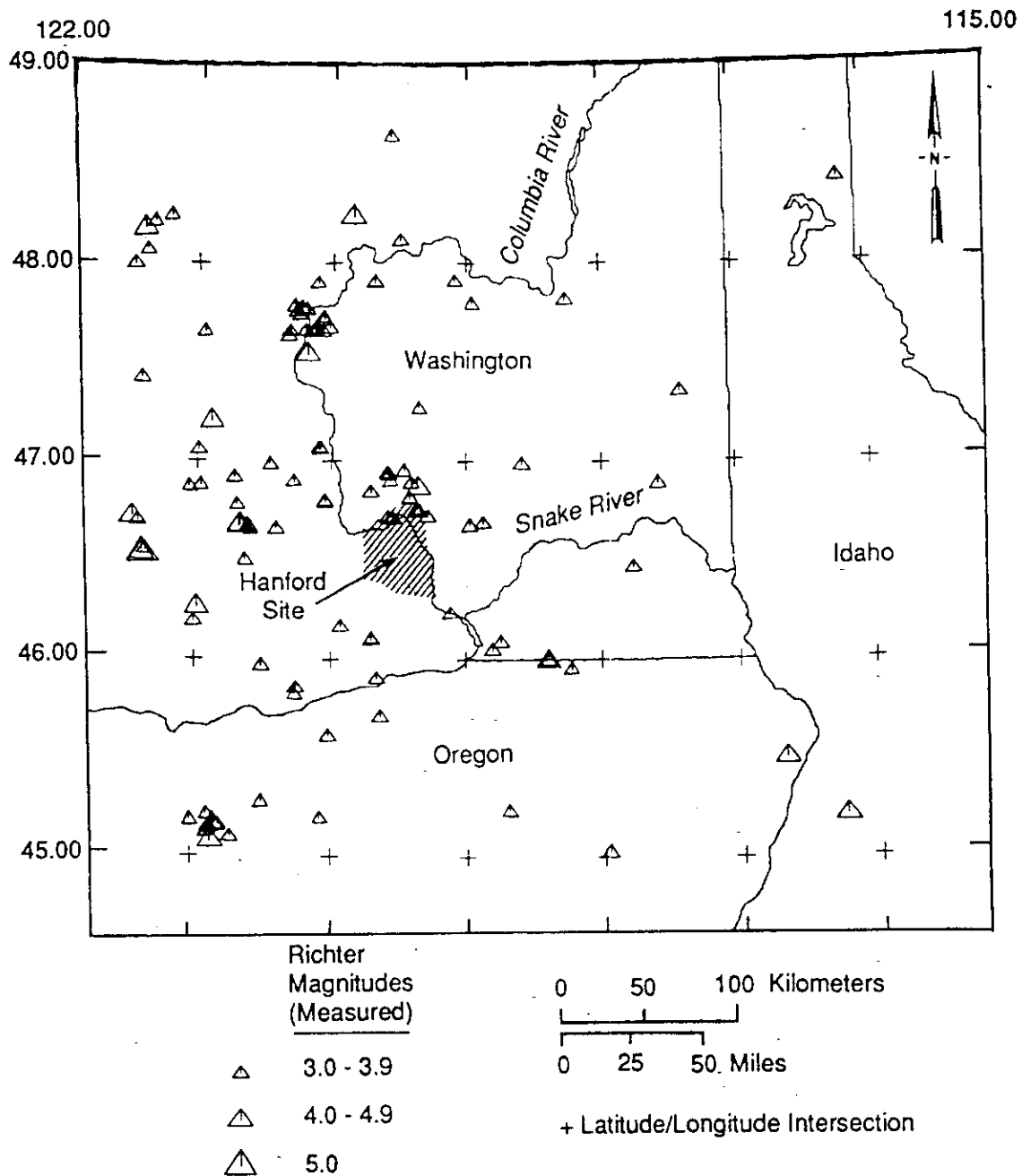


Figure 4.2-9. Recent seismicity of the Columbia Plateau and surrounding areas as measured by seismographs. All earthquakes between 1969 and 1986 with a Modified Mercalli Intensity \geq IV at magnitude \geq 3 are shown (Rohay 1989).

isolated events. Based on seismic refraction surveys in the region, the shallow earthquake swarms are occurring in the Columbia River Basalts, and the deeper earthquakes are occurring in crustal layers below the basalts.

The spatial pattern of seismicity in the central Columbia Plateau suggests an association of the shallow swarm activity with the east-west-oriented Saddle Mountains anticline. However, this association is complex, and the earthquakes do not delineate a thoroughgoing fault plane that would be consistent with the faulting observed on this structure.

Earthquake focal mechanisms in the central Columbia Plateau generally indicate reverse faulting on east-west planes, consistent with a north-south-directed maximum compressive stress and with the formation of the east-west-oriented anticlinal fold of the Yakima Fold Belt (Rohay 1987). However, earthquake focal mechanisms indicate faulting on a variety of fault plane orientations.

Earthquake focal mechanisms along the western margin of the Columbia Plateau also indicate north-south compression, but here the minimum compressive stress is oriented east-west, resulting in strike-slip faulting (Rohay 1987). Geologic studies indicate an increased component of strike-slip faulting in the western portion of the Yakima Fold Belt. Earthquake focal mechanisms in the Milton-Freewater region to the southeast indicate a different stress field, one with maximum compression directed east-west instead of north-south.

Estimates for the earthquake potential of structures and zones in the central Columbia Plateau have been developed during the licensing of nuclear power plants at the Hanford Site. In reviewing the operating license application for the Washington Public Power Supply System Project WNP-2, the Nuclear Regulatory Commission (NRC 1982) concluded that four earthquake sources should be considered for the purpose of seismic design: the Rattlesnake-Wallula alignment, Gable Mountain, a floating earthquake in the tectonic province, and a swarm area.

For the Rattlesnake-Wallula alignment, which passes along the southwest boundary of the Hanford Site, the NRC estimated a maximum magnitude of 6.5, and for Gable Mountain, an east-west structure that passes through the northern portion of the Hanford Site, a maximum magnitude of 5.0. These estimates were based upon the inferred sense of slip, the fault length, and/or the fault area. The floating earthquake for the tectonic province was developed from the largest event located in the Columbia Plateau, the magnitude 5.75 Milton-Freewater earthquake. The maximum swarm earthquake for the purpose of WNP-2 seismic design was a magnitude 4.0 event, based on the maximum swarm earthquake in 1973. (The NRC concluded that the actual magnitude of this event was smaller than estimated previously.)

The seismic design of WNP-2 is based upon a Safe-Shutdown Earthquake (SSE) of 0.25 gravity (g; acceleration). A probabilistic seismic exposure analysis was used to determine an annual probability of 1×10^{-4} for exceedance of 0.25 gravity (WPPSS 1981).

For the WNP-2 site, potential earthquakes associated with the Gable Mountain structure dominated the exceedance probability calculations compared with other potential sources that were considered.

4.2.2 Hydrology

4.2.2.1 Hydrology

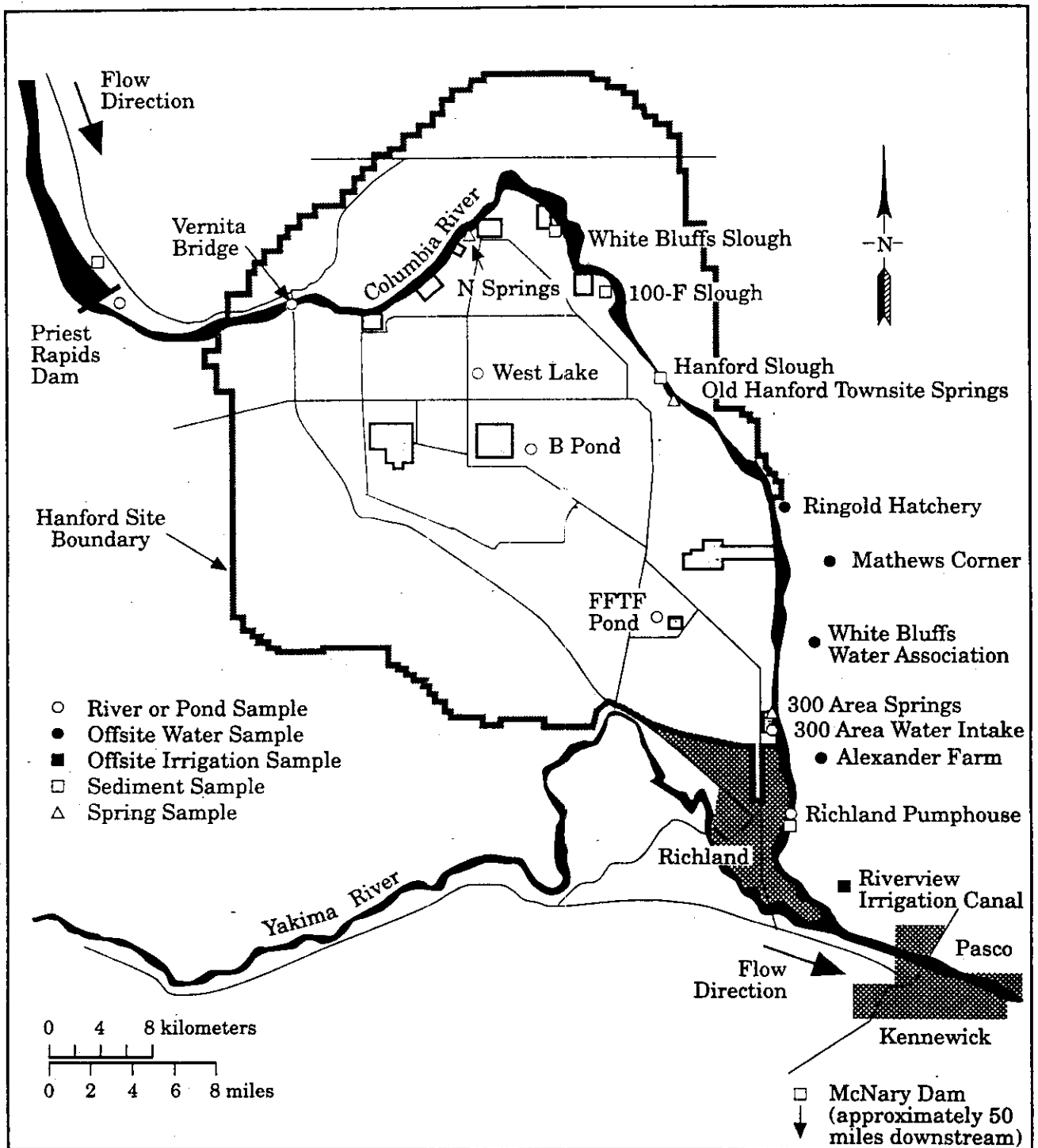
Surface Water. Surface water at Hanford includes the Columbia River (northern and eastern sections), riverbank springs along the river, springs on Rattlesnake Mountain, on-site ponds, and offsite water systems directly east of and across the Columbia River from the Hanford Site. In addition, the Yakima River flows along a short section of the southern boundary of the Site (Figure 4.2-10).

Columbia River. The Columbia River is the second largest river in North America and the dominant surface-water body on the Site. The original selection of the Hanford Site for plutonium production and processing was based, in part, on the abundant water provided by the Columbia River. The existence of the Hanford Site has precluded development of this section of river for irrigation and power, and the Hanford Reach is now currently under consideration for designation as a National Wild and Scenic River as a result of congressional action in 1988.

Originating in the mountains of eastern British Columbia, Canada, the Columbia River drains a total area of approximately 70,800 km² (27,300 mi²) en route to the Pacific Ocean. Flow of the Columbia River is regulated by 11 dams within the United States, 7 upstream and 4 downstream of the Site. Priest Rapids is the nearest dam upstream, and McNary is the nearest dam downstream. Lake Wallula, the impoundment created by McNary Dam, extends up to the vicinity of Richland, Washington. Except for its estuary, the only unimpounded stretch of the Columbia River in the United States, the Hanford Reach, extends from Priest Rapids Dam to the head of Lake Wallula.

Flows through the Reach fluctuate significantly and are controlled primarily by operations at Priest Rapids Dam. Annual average flows at the vicinity of Priest Rapids over the last 68 years have averaged nearly 3360 m³ (120,000 ft³) per second (McGavock et al. 1987). Daily average flows range from 1008 m³ to 7000 m³ (36,000 ft³ to 250,000 ft³) per second. Monthly mean flows typically peak from April through June during spring runoff from winter snows, and are lowest from September through October, accentuated by extensive river-water removal for irrigated agriculture in the Mid-Columbia Basin. As a result of fluctuations in discharges (called hydropeaking), the depth of the river varies significantly over time. Fluctuations of >5 vertical feet are not uncommon along the Reach (Dirkes 1993). The width of the river varies from approximately 300 m (984 ft) to 1000 m (3,281 ft) within the Hanford Site.

The primary uses of the Columbia River include the production of hydroelectric power and extensive irrigation in the Mid-Columbia Basin. Several communities located on the Columbia River rely on the river as their source of drinking water. Water from the Columbia River along the Hanford Reach is also used as a source of drinking water by



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Figure 4.2-10. Hanford Site showing Columbia and Yakima rivers (from Woodruff et al. 1993).

several onsite facilities and for industrial uses (Dirkes 1993). In addition, the Columbia River is used extensively for recreation, which includes fishing, hunting, boating, sailboarding, water-skiing, diving and swimming.

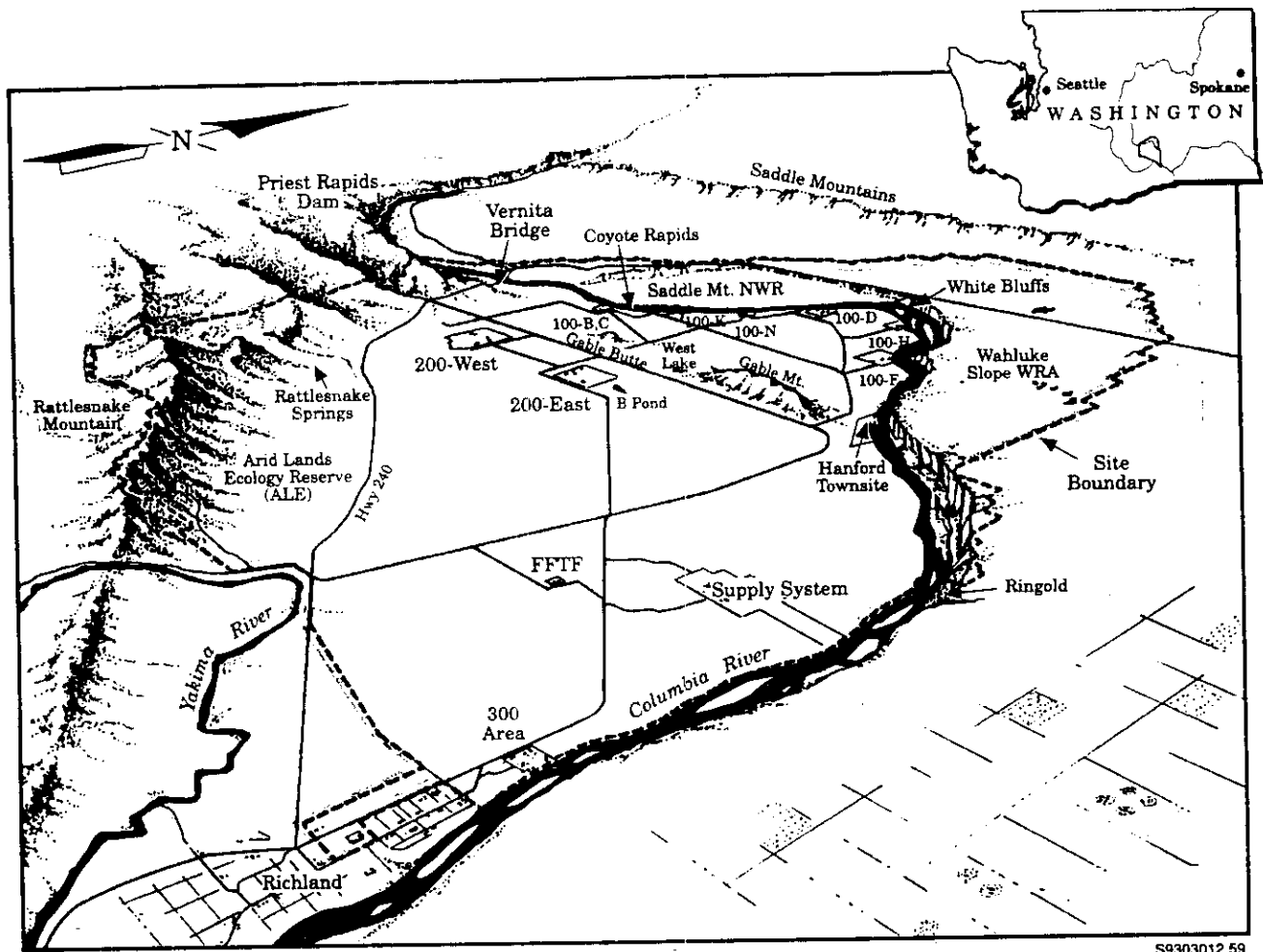
The Yakima River. The Yakima River, bordering a small length of the southern portion of the Hanford Site, has a low annual flow compared to the Columbia River. The average annual flow, based on nearly 60 years of records, is about 104 m^3 per second (cms) (3,712 cfs), with an average monthly maximum of 490 cms (17,500 cfs) and minimum of 4.6 cms (165 cfs). Approximately one-third of the Hanford Site is drained by the Yakima River System.

Springs and Streams. Rattlesnake and Snively Springs, located on the western part of the Site, form small surface streams. Rattlesnake Springs flows for about 3 km (1.6 mi) before disappearing into the ground (Figure 4.2-11). Cold Creek and its tributary, Dry Creek, are ephemeral streams within the Yakima River drainage system along the southern portion of the Hanford Site. These streams drain areas to the west of the Hanford Site and cross the southwestern part of the Site toward the Yakima River. Surface flow, when it occurs, infiltrates rapidly and disappears into the surface sediments in the western part of the Site.

Precipitation. Total estimated precipitation over the Pasco Basin is about $9 \times 10^8 \text{ m}^3$ annually, averaging $<20 \text{ cm/yr}$ (approximately 8 in./yr). Mean annual runoff from the Pasco Basin is estimated at $<3.1 \times 10^7 \text{ m}^3/\text{yr}$, or approximately 3% of the total precipitation. The basin-wide runoff coefficient is zero for all practical purposes. The remaining precipitation is assumed to be lost through evapotranspiration, with $<1\%$ recharging the groundwater system (DOE 1988). However, studies described by Gee et al. (1992) suggest that precipitation may contribute recharge to the ground water in areas where soils are coarse-textured and bare of vegetation. Studies by Gee et al. (1987), Gee and Kirkham (1984), and Gee and Heller (1985) provide information concerning natural recharge rates and evapotranspiration at selected locations on the Hanford Site.

Flooding. Large Columbia River floods have occurred in the past (DOE 1987), but the likelihood of recurrence of large-scale flooding has been reduced by the construction of several flood-control/water-storage dams upstream of the Site. Major floods on the Columbia River are typically the result of rapid melting of the winter snowpack over a wide area augmented by above-normal precipitation. The maximum historical flood on record occurred June 7, 1894, with a peak discharge at the Hanford Site of 21,000 cms (742,000 cfs). The flood plain associated with the 1894 flood is shown in Figure 4.2-12. The largest recent flood took place in 1948 with an observed peak discharge of 20,000 cms (706,280 cfs) at the Hanford Site. The probability of flooding at the magnitude of the 1894 and 1948 floods has been greatly reduced because of upstream regulation by dams (Figure 4.2-13).

There are no Federal Emergency Management Agency (FEMA) flood plain maps for the Hanford Reach of the Columbia River. FEMA only maps developing areas, and the Hanford Reach is specifically excluded.



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Figure 4.2-11. Hanford Site and surrounding area
(from Woodruff et al. 1993).

There have been fewer than 20 major floods on the Yakima River since 1862 (DOE 1986). The most severe occurred in November 1906, December 1933, and May 1948; discharge magnitudes at Kiona, Washington were 1870, 1900, and 1050 cms (66,000, 67,000, and 37,000 cfs), respectively. The recurrence intervals for the 1933 and 1948 floods are estimated at 170 and 33 years, respectively. The development of irrigation reservoirs within the Yakima River Basin has considerably reduced the flood potential of the river. Lands susceptible to a 100-year flood on the Yakima River are shown in Figure 4.2-14. Flooded areas could extend into the southern section of the Hanford Site, but the upstream Yakima River is physically separated from the Hanford Site by Rattlesnake Mountain which would prevent major flooding of the Hanford Site.

Evaluation of flood potential is conducted in part through the concept of the probable maximum flood, which is determined from the upper limit of precipitation falling on a

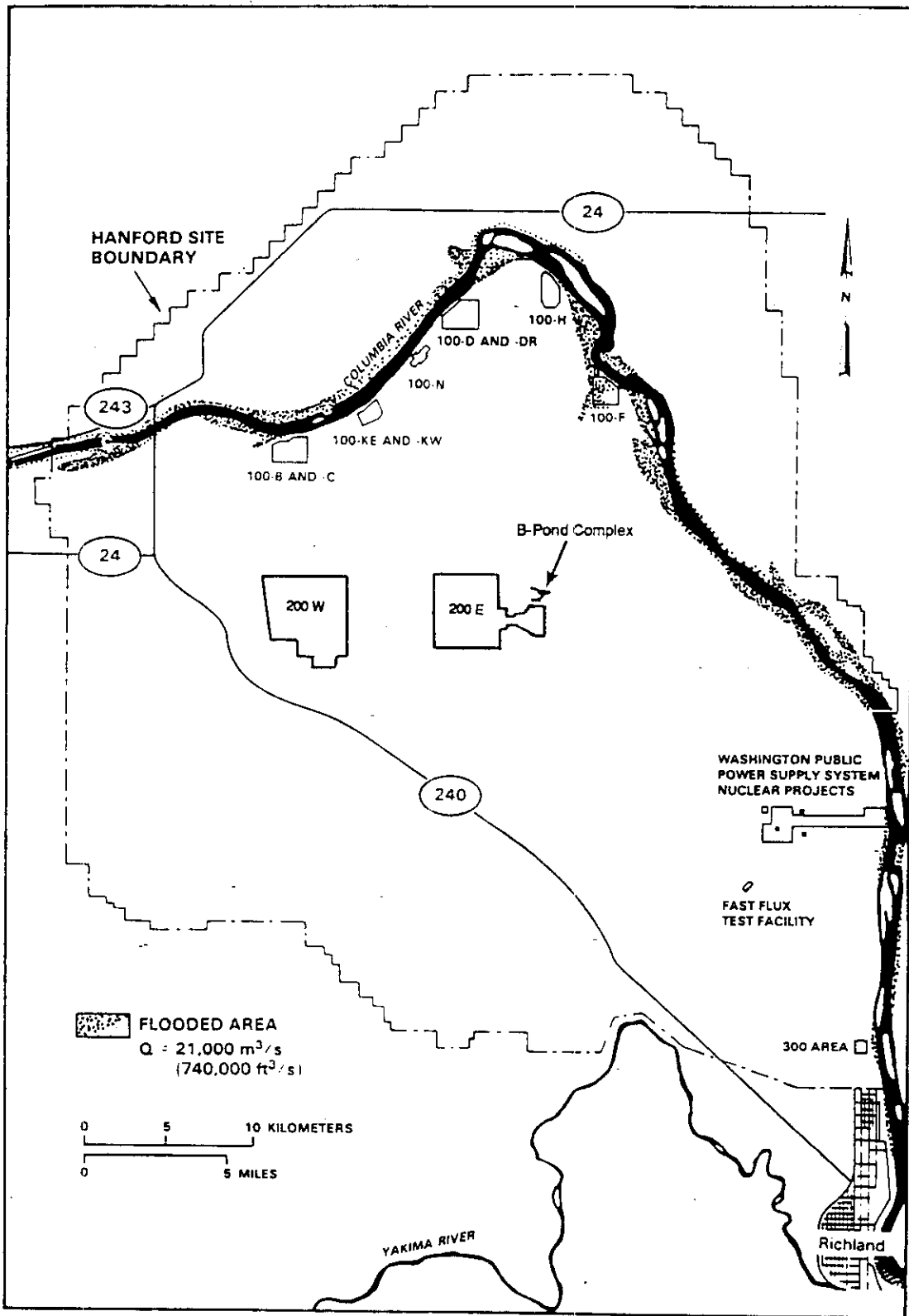


Figure 4.2-12. Flood area during the 1894 flood (DOE 1986).

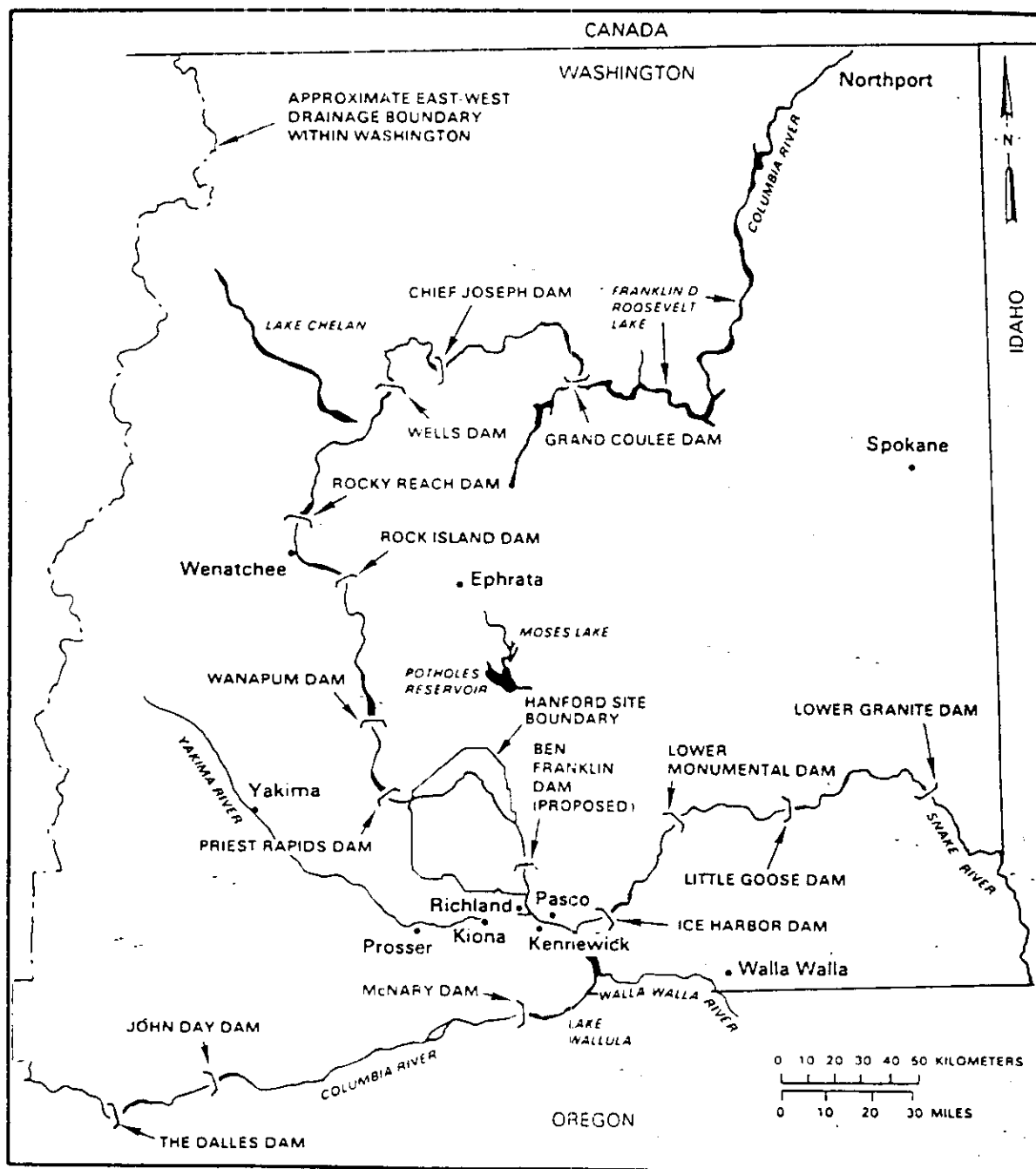


Figure 4.2-13. Locations of principal dams within the Columbia Plateau study area (DOE 1988)

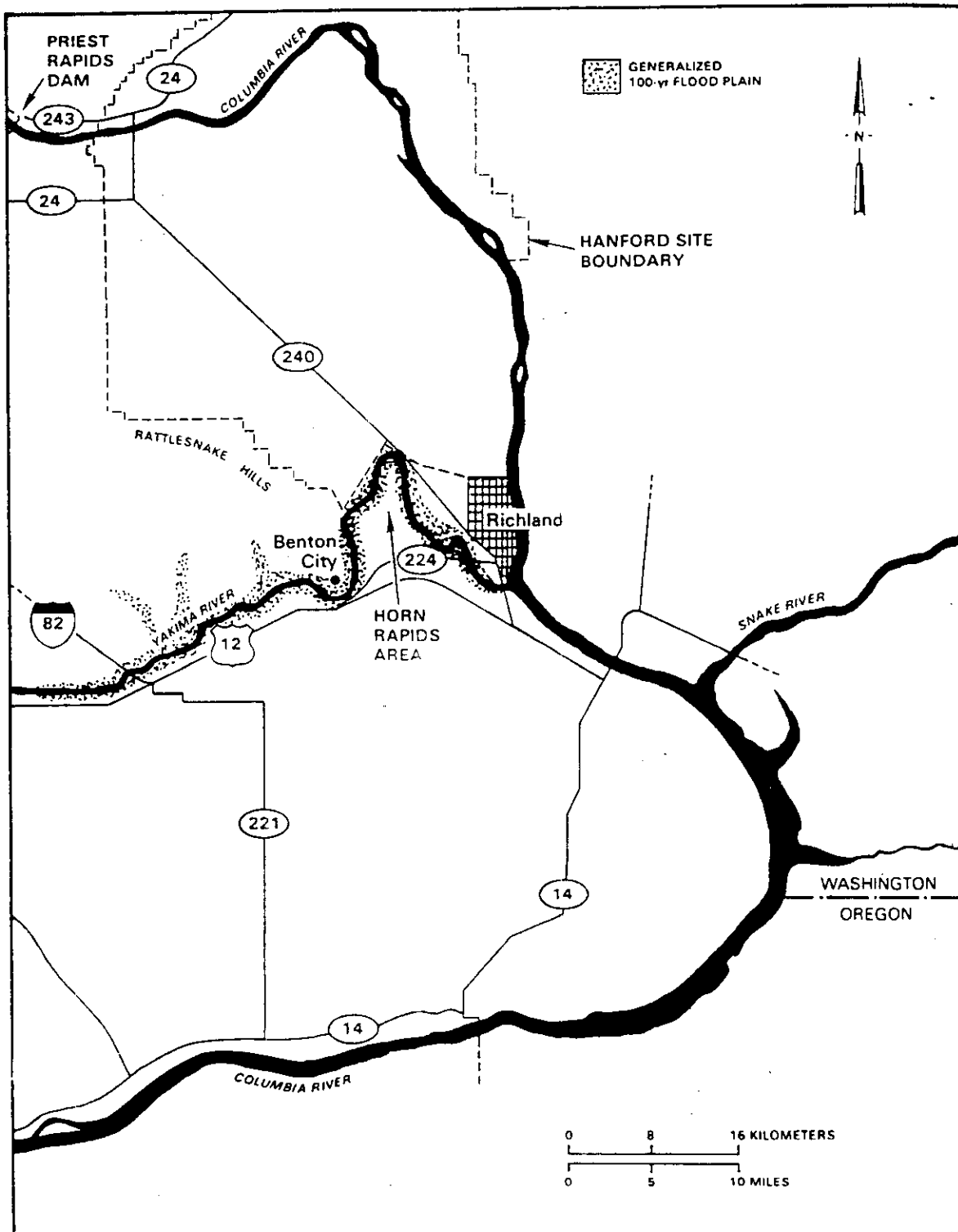


Figure 4.2-14. Flood area from a 100-year flood of the Yakima River in the vicinity of the Hanford Site (DOE 1986).

drainage area and other hydrologic factors, such as antecedent moisture conditions, snowmelt, and tributary conditions, that could result in maximum runoff. The probable maximum flood for the Columbia River below Priest Rapids Dam has been calculated to be 40,000 cms (1.4 million cfs) and is greater than the 500-year flood. The flood plain associated with the probable maximum flood is shown in Figure 4.2-15. This flood would inundate parts of the 100 Areas located adjacent to the Columbia River, but the central portion of the Hanford Site would remain unaffected (DOE 1986).

The U. S. Army Corps of Engineers (1989) has derived the Standard Project Flood (SPF) with both regulated and unregulated peak discharges given for the Columbia River below Priest Rapids Dam. Frequency curves for both natural (unregulated) and regulated peak discharges are also given for the same portion of the Columbia River. The regulated SPF for this part of the river is given as 15,200 cms (54,000 cfs) and the 100-year regulated flood as 12,400 cms (440,000 cfs). No maps for the flooded areas are given.

Potential dam failures on the Columbia River have been evaluated. Upstream failures could arise from a number of causes, with the magnitude of the resulting flood depending on the degree of breaching at the dam. The U. S. Army Corps of Engineers evaluated a number of scenarios on the effects of failures of Grand Coulee Dam, assuming flow - conditions of the order of 11,000 cms (400,000 cfs). For purposes of emergency planning, they hypothesized that 25% and 50% breaches, the "instantaneous" disappearance of 25% or 50% of the center section of the dam, would result from the detonation of nuclear explosives in sabotage or war. The discharge or floodwave resulting from such an instantaneous 50% breach at the outfall of the Grand Coulee Dam was determined to be 600,000 cms (21 million cfs). In addition to the areas inundated by the probable maximum flood (see Figure 4.2-15), the remainder of the 100 Areas, the 300 Area, and nearly all of Richland, Washington would be flooded (DOE 1986; see also ERDA 1976). No determinations were made for failures of dams upstream, for associated failures downstream of Grand Coulee, or for breaches >50% of Grand Coulee, for two principal reasons: 1) The 50% scenario was believed to represent the largest realistically conceivable flow resulting from either a natural or human-induced breach (DOE 1986), i.e., it was hard to imagine that a structure as large as the Grand Coulee Dam would be 100% destroyed instantaneously; and 2) it was also assumed that a scenario such as the 50% breach would occur only as the result of direct explosive detonation, and not because of a natural event such as an earthquake, and that even a 50% breach under these conditions would indicate an emergency situation in which there might be other overriding major concerns.

The possibility of a landslide resulting in river blockage and flooding along the Columbia River has also been examined for an area bordering the east side of the river upstream of the city of Richland. The possible landslide area considered was the 75-m (250-ft) high bluff generally known as White Bluffs. Calculations were made for an $8 \times 10^5 \text{ m}^3$ ($1 \times 10^6 \text{ yd}^3$) landslide volume with a concurrent flood flow of 17,000 cms (600,000 cfs) (a 200-year flood) resulting in a flood-wave crest elevation of 122 m (400 ft) above mean sea level. Areas inundated upstream of such a landslide event would be similar to those shown in Figure 4.2-15 (DOE 1986).

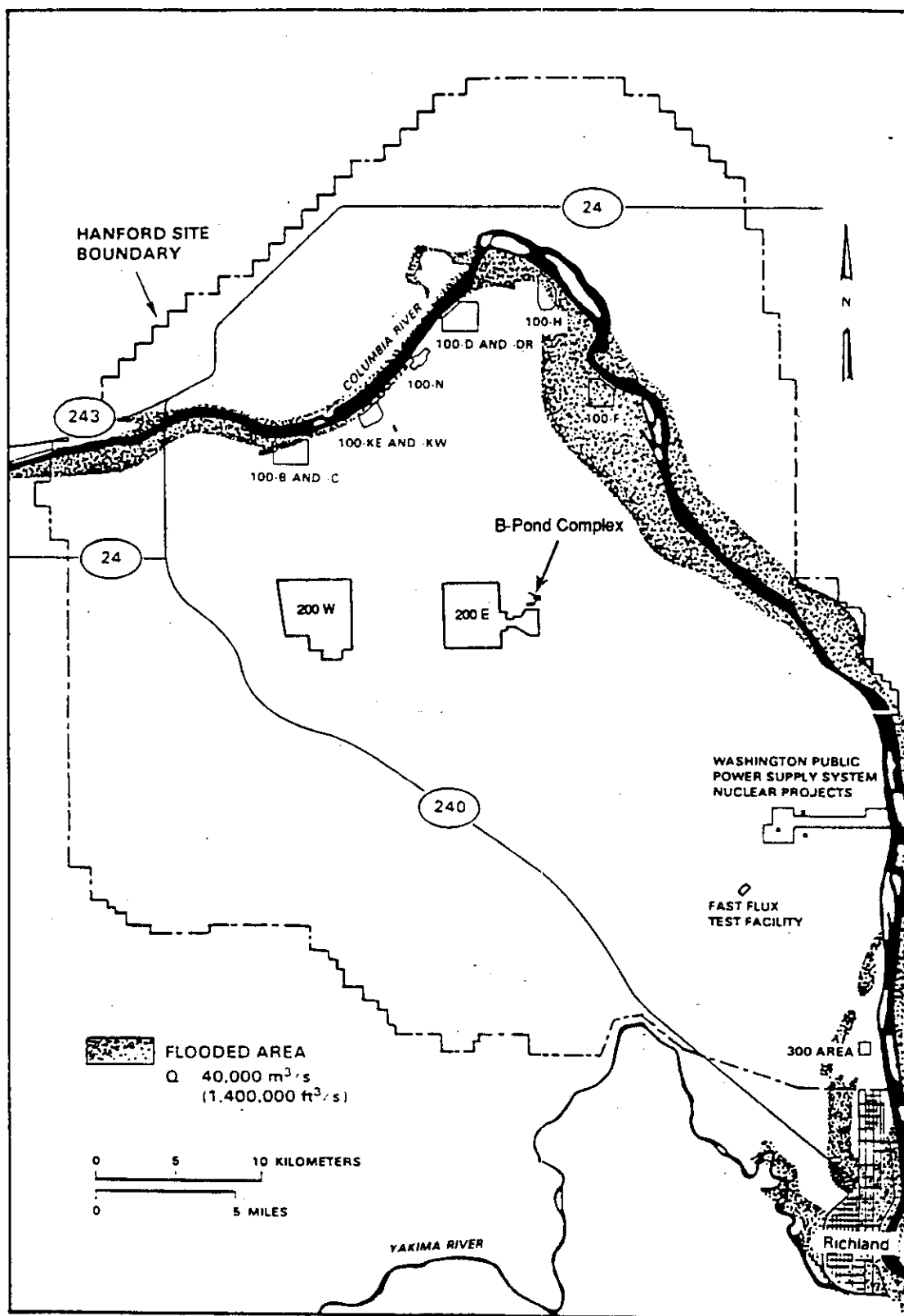


Figure 4.2-15. Flood area for the probable maximum flood (DOE 1986).

A flood risk analysis of Cold Creek was conducted in 1980 as part of the characterization of a basaltic geologic repository for high-level radioactive waste. Such design work is usually done according to the criteria of Standard Project Flood (SPF) or Probable Maximum Flood (PMF), rather than the worst-case or 100-year flood scenario. Therefore, in lieu of 100- and 500-year floodplain studies, a PMF evaluation was made for a reference repository location directly west of the 200-East area and encompassing the 200-West Area (Skaggs and Walters 1981). Schematic mapping indicates that access to the reference repository would be unimpaired but that Route 240 along the southwestern and western areas would not be usable (see Figure 4.2-16).

Columbia Riverbank Springs. The seepage of groundwater, or springs, into the Columbia River has been known to occur for many years. Riverbank spring discharges were documented along the Hanford Reach long before Hanford Operations began during the Second World War (Jenkins 1922). Riverbank springs are monitored for radionuclides at 100 N, the old Hanford townsite, and the 300 Area. These relatively small springs flow intermittently, apparently influenced primarily by changes in river level. Hanford-origin contaminants have been documented in these groundwater discharges along the Hanford Reach (Dirkes 1990; DOE 1992; McCormack and Carlile 1984; Peterson and Johnson 1992).

Onsite Ponds. Currently, there are three onsite ponds at the Hanford Site (see Figure 4.2-17). One is part of the B-Pond complex, located near the 200-East Area. It was originally excavated in the mid-1950s for disposal of process cooling water and other liquid wastes occasionally containing low levels of radionuclides. West Lake is located north of the 200-East Area, and is recharged from ground water (Gephardt et al. 1976). West Lake has not received direct effluent discharges from Site facilities; rather, its existence is caused from the elevated water table that intersects the land surface in the topographically low area south of Gable Mountain (and north of the 200-East Area). The artificially-elevated water table occurs under much of the Hanford Site and reflects the artificial recharge from Hanford Site operations (see Groundwater section below). The FFTF Pond is located near the 400 Area, and was excavated in 1978 for the disposal of cooling and sanitary water from various facilities in the 400 Area (Woodruff et al. 1993).

The ponds are not accessible to the public and did not constitute a direct offsite environmental impact during 1992 (Woodruff et al. 1993). However, the ponds are accessible to migratory waterfowl, creating a potential pathway for the dispersion of contaminants. Periodic sampling provides an independent check on effluent control and monitoring systems (Woodruff et al. 1993).

Offsite Water. Other than rivers and springs, there are no naturally-occurring bodies of surface water adjacent to the Hanford Site. However, there are artificial wetlands, caused by irrigation, on the east and west sides of the Waluke Slope portion of the Hanford Site, which lies north of the Columbia River. Hatcheries and canals associated with the Columbia Basin Irrigation Project constitute the only other artificial surface-water expressions in the area. The Ringold Hatchery is the only local hatchery, just south of the Hanford Site boundary on the east side of the Columbia River (just north of the 300 Area).

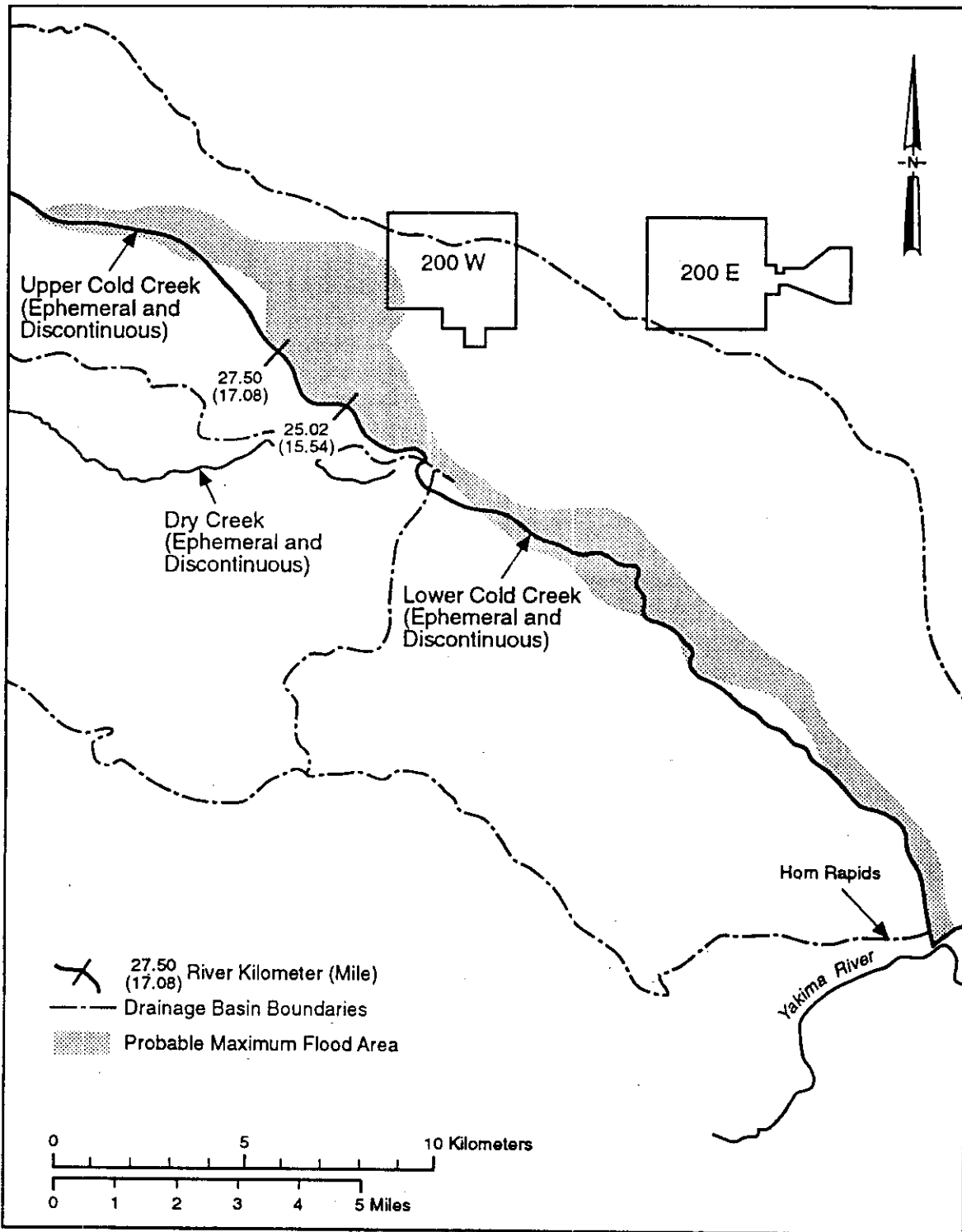
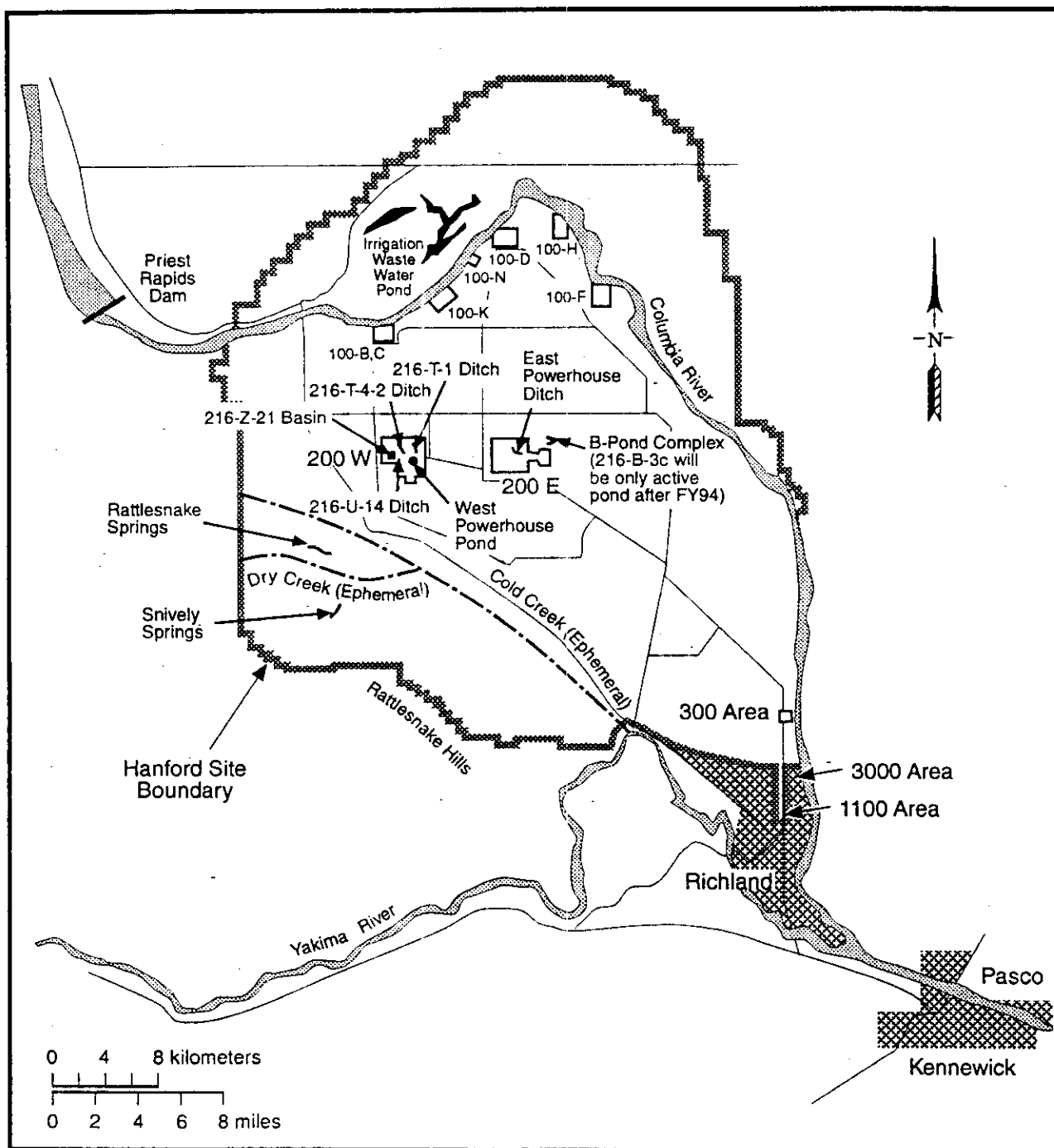


Figure 4.2-16. Extent of probable maximum flood in Cold Creek Area
(after Skaggs and Walters 1981).



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Figure 4.2-17. Temporary ponds and ditches, including ephemeral streams, on the Hanford Site.

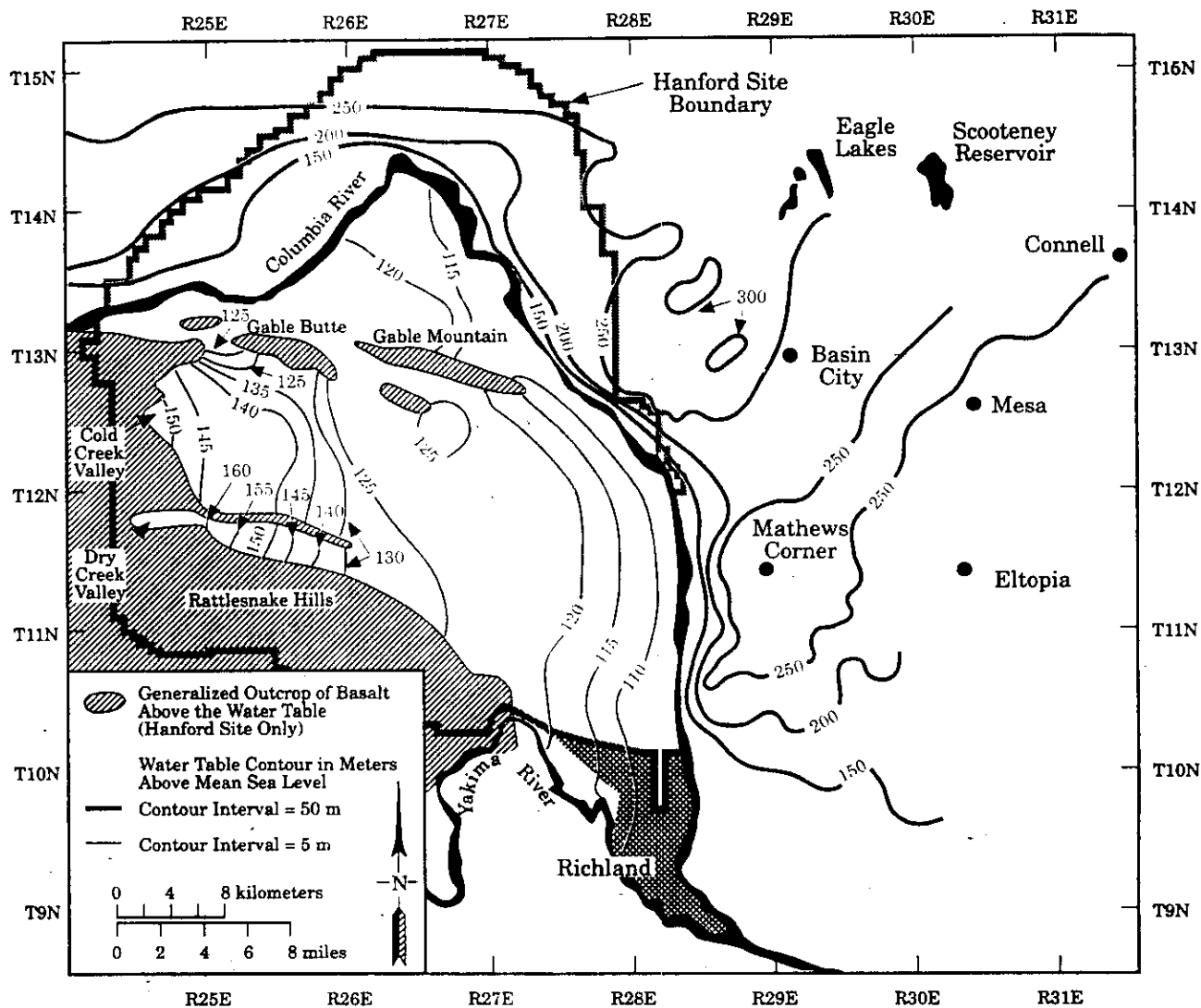
The Riverview Irrigation Canal is currently being sampled for possible "downwind" airborne contamination and is representative of the extensive canal system in Central and Eastern Washington.

Groundwater. Groundwater is but one of the many interconnected stages of the hydrologic cycle. Essentially all groundwater, including Hanford's, originates as surface water either from natural recharge such as rain, streams and lakes, or from artificial recharge such as reservoirs, excess irrigation, canal seepage, deliberate augmentation, industrial processing, and waste-water disposal.

Hanford Site Aquifer Systems. The unconfined aquifer is also referred to as the upper or suprabasalt aquifer system because portions of the upper aquifer system are locally confined or semiconfined, and because in the 200 East Area the unconfined system is in communication with the confined system. However, because the entire suprabasalt aquifer system is interconnected on a sitewide scale, it will be called the Hanford unconfined aquifer for the purpose of this report. Aquifers located within the Columbia River Basalts are referred to as the confined aquifer system. The following presentation of the Hanford Site aquifer systems is taken from Thorne and Chamness (1992).

Confined Aquifer System. Confined aquifers within the Columbia River Basalts are within relatively permeable sedimentary interbeds and the more porous tops and bottoms of basalt flows. The horizontal hydraulic conductivities of most of these aquifers fall in the range of 10^{-10} to 10^{-4} m/s. Saturated but relatively impermeable dense interior sections of the basalt flows have horizontal hydraulic conductivities ranging from 10^{-15} to 10^{-9} m/s, about five orders of magnitude lower than those of the confined aquifers (DOE 1988). Hydraulic-head information indicates that groundwater in the confined aquifers flows generally toward the Columbia River and, in some places, toward areas of enhanced vertical flow communication with the unconfined system (Bauer et al. 1985; Spane 1987; DOE 1988). The confined aquifer system is important because it is known to be in hydraulic communication with the unconfined aquifer in the area northeast of the 200-East Area (Graham et al. 1984), and because there is a potential for significant groundwater leakage between the two systems. No data quantifying the leakage between the upper confined and unconfined aquifers are available. Head relationships presented in previous reports (DOE 1988) demonstrate the potential for such leakage. Water chemistry data indicating that interaquifer leakage has taken place in areas of increased vertical communication also have been presented in published reports (Graham et al. 1984; Jensen 1987).

Unconfined Aquifer. Groundwater in the unconfined aquifer at Hanford generally flows from recharge areas in the elevated region near the western boundary of the Hanford Site toward the Columbia River on the eastern and northern boundaries (Figure 4.2-18). The Columbia River is the primary discharge area for the unconfined aquifer. The Yakima River borders the Hanford Site on the southwest and is generally regarded as a source of



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Figure 4.2-18. Water-table elevations for the unconfined aquifer at Hanford, June 1993 (from Woodruff et al. 1993).

recharge. Natural areal recharge from precipitation across the entire Hanford Site is thought to range from about 0-10 cm/yr (0-4 in./yr), but is probably <2.5 cm/yr (1 in./yr) over most of the site (Gee and Heller 1985; Bauer and Vaccaro 1990). Since 1944, the artificial recharge from Hanford waste-water disposal operations has been significantly greater than the natural recharge. An estimated 1.68×10^{12} L of liquid was discharged to disposal ponds, trenches, and cribs in this period.

Horizontal hydraulic conductivities of sand and gravel facies within the Ringold Formation generally range from about 10^{-5} to 10^{-4} m/s (10-102 ft/day) (DOE 1988). Because the Ringold sediments are more consolidated and partially cemented, they are about 10 to 100 times less permeable than the sediments of the overlying Hanford formation. Prior to waste-water disposal operations at the Hanford Site, the uppermost aquifer was mainly within the Ringold Formation and the water table extended into the Hanford formation at only a few locations (Newcomb et al. 1972). However, waste-water discharges have raised the water-table elevation across the site and created groundwater mounds under the two main waste-water disposal areas in the 200 Areas. Because of the general increase in groundwater elevation, the unconfined aquifer now extends upward into the Hanford formation. This change has resulted in an increase in groundwater transmissivity not only because of the greater volume of groundwater but also because the newly saturated sediments are highly permeable.

Since the beginning of Hanford operations in 1943, the water table has risen about 27 m (89 ft) under at least one disposal area in the 200 West Area and about 9 m (30 ft) under disposal ponds near the 200 East Area. The volume of water that has been discharged to the ground at the 200-West Area is actually less than that discharged at 200 East. However, the lower conductivity of the aquifer in the vicinity of the 200 West Area has inhibited groundwater movement in this area and resulted in a higher groundwater mound. The presence of the groundwater mounds has locally affected the direction of groundwater movement, causing radial flow from the discharge areas. Zimmerman et al. (1986) documented changes in water-table elevation between 1950 and 1980. They showed that the edge of the mounds migrated outward from the sources over time until about 1980. Water levels have declined in some areas since 1980 because of decreased wastewater discharges (Newcomer 1990).

Limitations of Hydrogeology Information. The sedimentary architecture of the unconfined aquifer is very complex because of repeated deposition and erosion that have occurred in this area. Although hundreds of wells have been drilled on the Hanford Site, many penetrate only a small percentage of the total unconfined aquifer thickness, and there is a limited number of useful wells for defining the deeper facies. A number of relatively deep wells were drilled in the early 1980s as part of a study for a proposed nuclear power plant (PSPL 1982), and these data are useful in defining facies architecture. For most of the thinner and less extensive sedimentary units, correlation between wells is either not possible or uncertain.

A limited amount of hydraulic property data is available from testing of wells. Hydraulic test results from wells on the Hanford Site have been compiled for the Ground-Water Surveillance Project and for environmental restoration efforts in the 200 Areas (WHC data

packages) (Thorne and Newcomer 1992; Thorne et al. 1993; Kipp and Mudd 1973). Depths of the tested intervals have been correlated with the top of the unconfined aquifer as defined by the water-table elevations presented in Newcomer et al. (1991). Most hydraulic tests were done within the upper 15 m (49 ft) of the aquifer, and many were open to more than one layer. In some cases, changes in water-table elevation may have significantly changed the unconfined aquifer transmissivity at a well since the time of the hydraulic test. Only three hydraulic tests within the Hanford Site have resulted in estimates of aquifer specific yield.

Natural Groundwater Quality. Groundwater chemistry in the confined aquifer units displays a range, depending upon depth and residence time, from a calcium and magnesium carbonate water to a sodium and chloride carbonate water. Some of the shallower confined aquifers in the region (e.g., the Wanapum basalt aquifer at <300 m [984 ft]) have exceptionally good water-quality characteristics: <300 mg/L dissolved solids; <0.1 mg/L iron and magnesium; <20 mg/L sodium, sulfate and chloride; and <10 ppb heavy metals (Johnson et al. 1992).

Groundwater Residence Times. Tritium and carbon-14 measurements indicate that residence or recharge time (length of time required to replace the groundwater) takes tens to hundreds of years for spring waters, from hundreds to thousands of years for the unconfined aquifer, and more than 10,000 years for groundwaters in the shallow confined aquifer (Johnson et al. 1992). Chlorine-36 and noble gas isotope data suggest ages greater than 100,000 years for groundwaters in the deeper confined systems (Johnson et al. 1992). These relatively long residence times are consistent with arid-site recharge conditions and point to the need for conservation. For example, in the western Pasco Basin extensive agricultural groundwater use of the Priest Rapids Member (recharge time >10,000 years) has lowered the potentiometric surface >10 m (33 ft) over several square miles to the west of the Hanford Site. Continued excessive withdrawals along the western edge of the Pasco Basin could eventually impact the confined-aquifer flow directions beneath the 200 West Area of the Hanford Site (Johnson et al. 1992).

Hydrology East and North of the Columbia River. The Hanford Site boundary extends to the east and north of the Columbia River in order to provide a buffer zone for non-Hanford activities such as recreation and agriculture. Hanford Site activities in these areas have not impacted the groundwater. However, the groundwater is impacted by high artificial recharge from irrigation practices and leaky canals. The outlying areas east and north of the Columbia River are irrigated by the South Columbia Basin Irrigation District, which is part of the Columbia Basin Irrigation District, and artificial recharge has elevated the water table throughout the Pasco Basin, in some places by as much as 92 m (300 ft) (Drost et al. 1989).

There are two general hydrologic areas that impinge upon the Hanford Reservation boundaries to the east and north of the river. The eastern area extends from north to south between the lower slope of the Saddle Mountains and the Esquatzel Diversion canal and includes the Ringold Coulee, White Bluffs area, and Esquatzel Coulee. The water table occurs in the Pasco Gravels in both the Ringold and Esquatzel Coulee, and Brown (1979) reported that runoff from spring discharge at the mouth of Ringold Coulee is

> 10,000 gpm. Elsewhere the unconfined aquifer is in the less-transmissive Ringold Formation. Irrigation has also resulted in a series of springs issuing from perched water along the White Bluffs, and subsequent slumping and landslides. Irrigation on the Wahluke Slope and the area east of the Columbia River has created perched water tables in addition to very steep hydraulic gradients (Newcomer et al. 1992; Brown 1979).

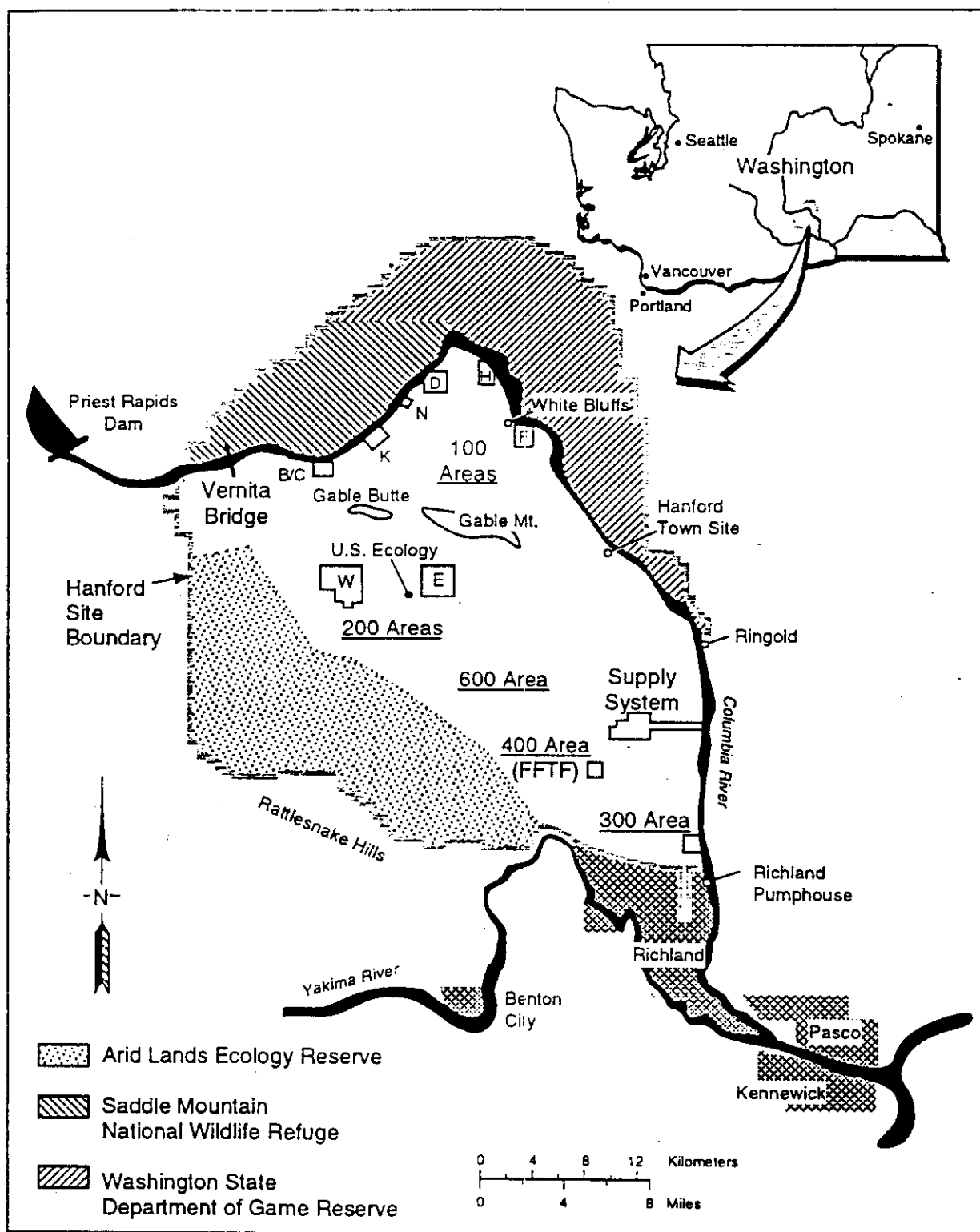
The other principal area of irrigation is the northern part of the Pasco Basin on the Waluke Slope between the Columbia River and the Saddle Mountain anticline. Irrigation on Waluke Slope north of the Columbia River has created ponds and seeps in the Saddle Mountain Wildlife Refuge. The major unconfined groundwater flow is downward movement from the anticlinal axes of the basalt ridges towards the Columbia River where it flows within a syncline. Bauer et al. (1985) reported that lateral water table gradients are essentially equal to or slightly less than the structural gradients on the flanks of the anticlinal fold mountains where the basalt dips steeply.

4.2.2.2 Water Quality

Columbia River. The State of Washington has classified the stretch of the Columbia River from Grand Coulee to the Washington-Oregon border, which includes the Hanford Reach, as Class A, Excellent (Ecology 1992). Class A waters are to be suitable for essentially all uses, including raw drinking water, recreation, and wildlife habitat. State and federal drinking water standards apply to the Columbia River and are currently being met.

Water samples were collected from the Columbia River along cross sections established at the Vernita Bridge upstream of the Hanford Site, and at the Richland City Pump house downstream of the Hanford Site, during the last 4 months of 1991 and quarterly throughout 1992 (Figure 4.2-19). The results of this recent study showed that water temperature, pH, and conductivity were within the range observed by the USGS during the course of their national water-quality investigations (McGavock et al. 1987; Woodruff et al. 1993). Water temperature measured at the pump outlet ranged from 6.6 to 22.8 °C (12 to 41 °F) for all locations, with little difference between sampling locations. The current major source of heat to the Columbia River in the Hanford Reach is solar radiation (Dauble et al. 1987). Differences between river temperatures at Priest Rapids Dam and the Richland Pump house during 1992, in the absence of reactor operations, were similar to those in the past (Price 1986).

The average pH values ranged from 7.3 to 8.6 for all samples with no apparent difference between locations. Mean conductivity values of 112 to 191 uS were similar at both locations (Dirkes et al. 1993).



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Figure 4.2-19. Sites of Columbia River chemical monitoring (from Dirkes et al. 1993).

Radionuclides consistently detected in the river during 1992 were ^3H , ^{90}Sr , ^{129}I , ^{234}U , and ^{238}U . In addition, ^{99}Tc , ^{238}U , and $^{239/240}\text{Pu}$ were detected in $\geq 50\%$ of samples analyzed during the year. Total alpha and beta measurements (useful indicators of the general radiological quality of the river and provide an early indication of changes in radioactive contamination levels because results are obtained quickly) were similar to previous years, and were approximately 5% or less of the applicable drinking water standards of 15 and 50 pCi/L, respectively. Tritium measurements, well below state and federal drinking water standards, indicate there is a concentration gradient across the Columbia River at the Richland Pump house. This is interpreted to be caused by incomplete mixing of the 200-Area groundwater plume that enters the river at the 300 Area (Backman 1962; Dirkes 1993).

All non-radiological water quality standards were met for Class A-designated water (Bisping and Woodruff 1993).

4.2.2.3 Environmental Monitoring

The DOE has conducted an environmental monitoring program at the Hanford Site for the past 48 years. The monitoring results have been recorded from 1946 to 1958 in quarterly reports. Since 1958, the results have been available as annual reports (summarized by Soldat et al. 1986). For calendar year 1992, the monitoring results for offsite and onsite environs and for onsite groundwater are combined in one PNL report (Woodruff et al. 1993).

Radioactive materials in air were sampled continuously on the Hanford Site, at the Hanford Site perimeter, and in nearby and distant communities in the Columbia Basin in a total of 42 locations. The air pathway sampling resulted in a potential dose to the maximally exposed individual that was 0.04% of the EPA limit (Woodruff et al. 1993).

Groundwater was collected from 720 wells in 1992 that sampled both the confined and unconfined aquifers beneath the Hanford Site. The major plume of tritium-contaminated groundwater continued to move eastward, resulting in seepage into the Columbia River. Samples of Columbia River water were collected immediately upstream and downstream of the Hanford Site. Concentrations of all radionuclides observed in river water were all well below applicable EPA and state of Washington drinking-water standards (Woodruff et al. 1993).

Foodstuffs from the area, including those irrigated with Columbia River water, were sampled. Although concentrations of most specific radionuclides were below detectable limits, low levels of tritium, strontium-90, iodine-129, and cesium-137 were found in a number of foodstuffs collected in 1992. Details can be found in Woodruff et al. (1993).

Deer, rabbits, game birds, waterfowl, and fish were also collected and analyzed; results were similar to those in recent years (Woodruff et al. 1993). Game birds, waterfowl, fish, and deer showed low levels of cesium-137 attributable to Hanford operations. Other concentrations of radionuclides were typical of levels attributable to worldwide weapon-test fallout.

Low concentrations of radionuclides were measured in samples of soil and vegetation during 1992. The levels were similar to those obtained in previous years, and no discernible increase in concentration could be attributed to current Hanford operations. Dose rates from external penetrating radiation measured in the vicinity of local residential areas were similar to those observed in previous years, and no contribution from Hanford activities could be identified.

Certain chemicals for which drinking water standards (DWS) have been set by the EPA and the state of Washington were also present in Hanford groundwater near operating areas. The following summary of chemical concentrations is from Woodruff et al. (1993). Nitrate was measured at concentrations greater than the DWS (45 mg/L as NO_3 ion) in wells in all operational areas except the 100-B and 400 Areas. Nitrate concentrations greater than DWS were widespread in groundwater beneath the 200-W Area. Fluoride was detected at levels greater than the primary DWS (4.0 mg/L) in the 200-W Area and greater than the secondary standard (2.0 mg/L) in the 200-E and 200-W Areas. Chromium concentrations exceeding DWS have been found in groundwater samples throughout most of the Hanford Site. Carbon tetrachloride contamination was found in the unconfined aquifer beneath much of the 200-W Area. The distribution of carbon tetrachloride in the 200-W Area has remained relatively stable since its existence was first noted in 1987. In addition to carbon tetrachloride, significant amounts of other chlorinated hydrocarbon solvents were found in 200-W Area groundwater, including trichloroethylene and chloroform. Tetrachloroethylene, also referred to as perchloroethylene, is found at levels greater than the DWS in a number of areas of the Site. Sampling at monitoring wells near Richland water supply wells showed that concentrations of regulated groundwater constituents in this area are below DWS and in general below detection levels (Dresel et al. 1993).

Measured and calculated radiation doses to the general public from Hanford operations were well below applicable regulatory limits throughout 1992. The potential dose to the hypothetical maximally-exposed individual from 1992 operations was about 0.02 millirem, the same as reported for 1991, and 0.01 millirem lower than the 1990 dose. The potential dose to the local population of 380,000 persons was 0.8 person-rem as compared with 0.9 person-rem in 1991 (Woodruff et al. 1993). The 1992 average dose to the population was 0.002 millirem. These doses are much lower than doses potentially received by the general public from other common sources of radiation (Figure 4.2-20). The current DOE radiation limit for an individual member of the public is 100 millirem/yr, and the average dose from natural sources is 300 millirem/yr (Woodruff et al. 1993).

4.2.3 100 Areas Geology and Hydrology

Geology

The 100 Areas are spread out along the Columbia River in the northern portion of the Pasco Basin. Figure 4.2-21 shows the location of cross sections through the 100 Areas.

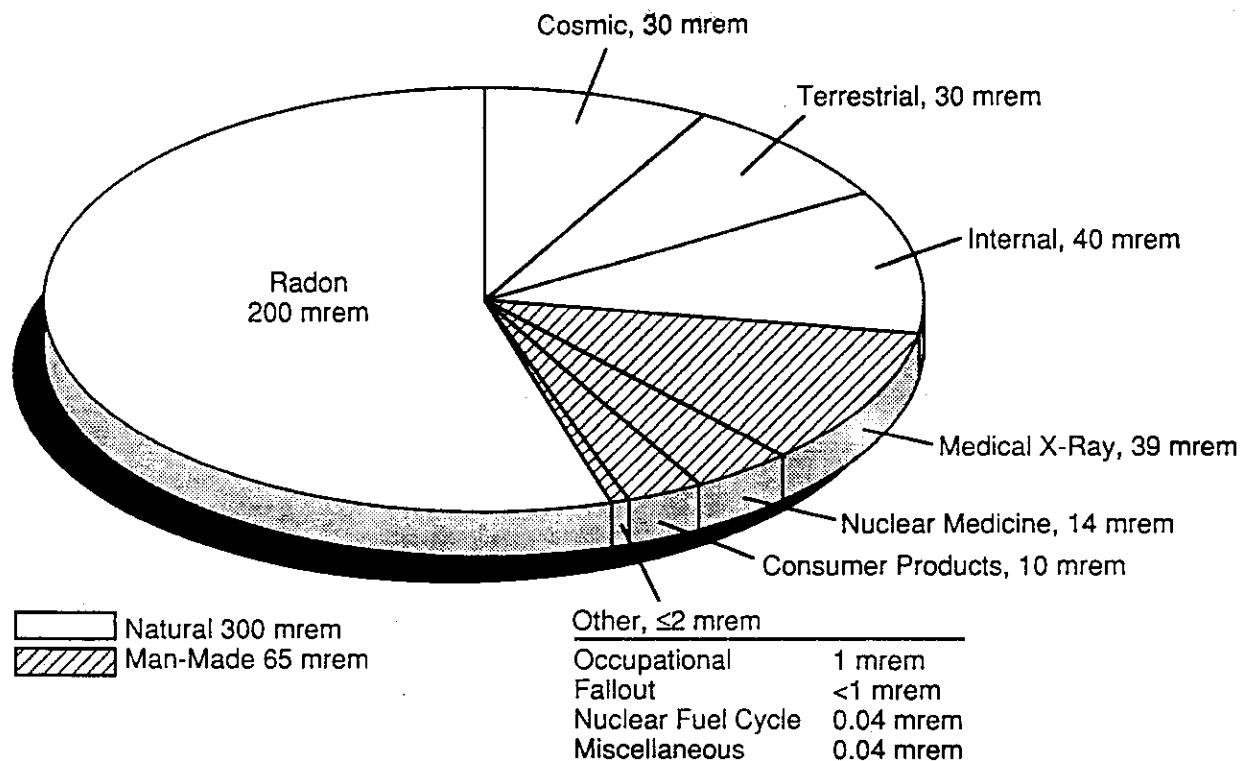


Figure 4.2-20. Annual radiation doses from various sources (NCRP 1987).

All of the 100 Areas, except the 100 B/C Area, lie on the north limb of the Wahluke syncline. The 100 B/C Area lies over the axis of the syncline. The top of basalt in the 100 Areas ranges in elevation from 46 m (150 ft) near 100 H Area to -64 m (-210 ft) below sea level near 100 B/C Area. The Ringold and Hanford formations occur throughout this area, while the pre-Missoula gravels are present in the western portion of the area; the Plio-Pleistocene unit and early "Palouse" soil have not been recognized in the 100 Areas.

The Ringold Formation shows a marked west-to-east variation in the 100 Areas (Lindsey 1992). The main channel of the ancestral Columbia River flowed along the front of Umtanum Ridge and through the 100 B/C and 100 K areas, before turning south to flow along the front of Gable Mountain and/or through the Gable Mountain-Gable Butte gap. This main channel deposited coarse-grained sand and gravel facies of the Ringold Formation (Units A, B, C and E). Further to the north and east, however, the Ringold sediments gradually become dominated by the lacustrine and overbank deposits and associated paleosols (Ringold Lower Mud Sequence and unnamed units), with the 100 H Area showing almost none of the gravel facies. The pre-Missoula gravels have not been extensively identified in the 100 Areas. At that time, the river apparently flowed from along the front of Umtanum Ridge through the Gable Mountain-Gable Butte gap, leaving relatively thin deposits of sand and gravel in the 100 B/C and K Areas. In the

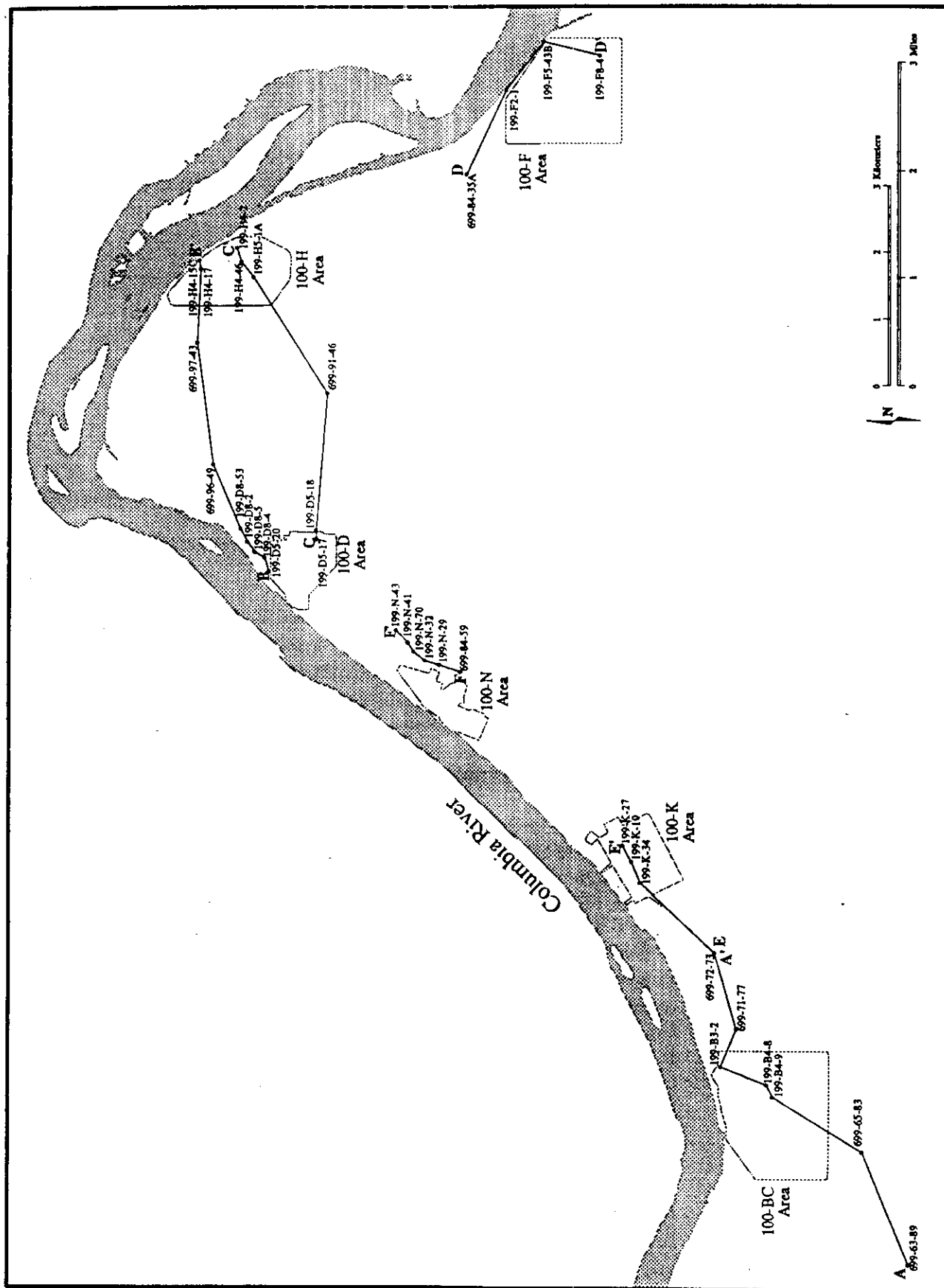


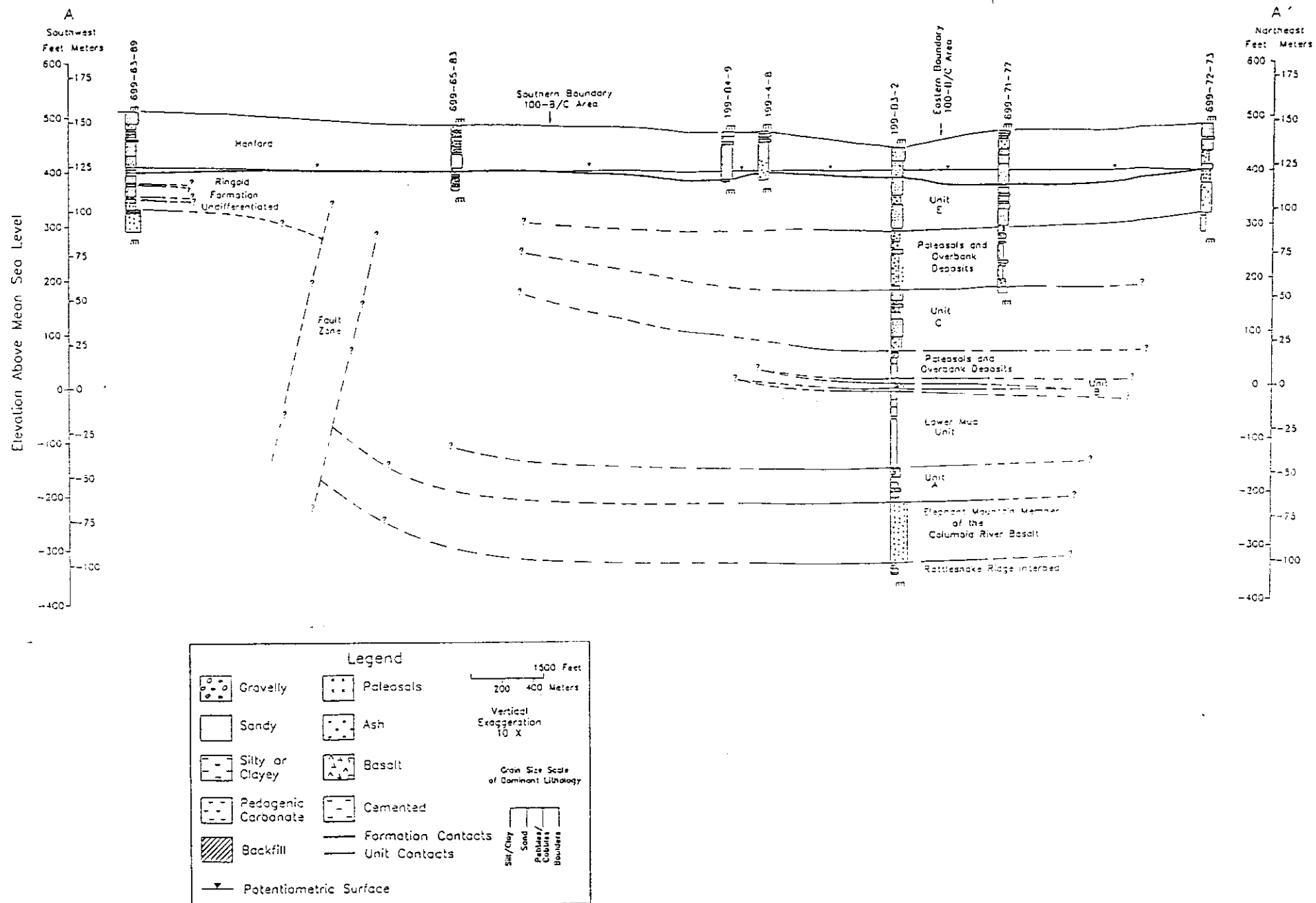
Figure 4.2-21. Location map for 100 Areas cross sections.

100 Areas, the Hanford formation consists primarily of Pasco Gravels facies, with local occurrences of the sand-dominated or slackwater facies. Brief detailed descriptions of each of the 100 Areas are given below.

100 B/C Area. In the 100 B/C Area, depth to basalt is approximately 183 m (600 ft). Lindberg (1993a) has recently evaluated the geology in the 100 B/C Area, and much of the following information is from that report. Figure 4.2-22 provides a cross-section of the area showing general relationships between the following units. Unit A is the lowest Ringold unit, overlying the basalt throughout the area and probably pinching out to the south against the Gable Mountain anticlinal structure. This unit consists of nearly 18 m (60 ft) of fluvial sands and gravels. Above Unit A are 44 m (143 ft) of lacustrine muds and overbank/paleosol deposits comprising the Lower Mud Sequence. In this area, a thin (10 m [32 ft] thick) Unit B overlies the Lower Mud Sequence, and consists of alternating layers of gravelly sand and overbank/paleosol muds. Above this is a 15-m (50-ft) sequence of overbank/paleosol muds with occasional sand or gravel lenses. Unit C lies above this mud, and contains 35 m (113 ft) of fluvial sand and gravel. Another unnamed mud unit overlies Unit C, and consists of 34 m (110 ft) of paleosols and overbank deposits. Unit E is the uppermost Ringold unit present in the 100 B/C Area, and ranges from 14 to 40 m (45 to 130 ft) thick. Variations in thickness are due to erosion before or during cataclysmic flooding and the possibility that Units B or C have been incorporated in places where the separating mud is not present.

Overlying Ringold Formation Unit E throughout the 100 B/C Area is the Pasco Gravel facies of the Hanford formation. The thickness of the Hanford formation ranges from 15 to 30 m (50 to 100 ft), with the thinnest area occurring near the Columbia River. The uppermost half of the unit is often a boulder gravel. Recent river deposits are extensive in the northwestern part of the site, with overbank deposits found in abandoned or intermittently active channels. Windblown sands form a thin, discontinuous blanket over much of the area. The water table in the 100 B/C Area is found within the lower portions of the Hanford formation.

100 D Area. The top of basalt in the 100 D Area is approximately 125 m (410 ft) below ground. No boreholes penetrate the entire suprabasalt sequence, and the stratigraphic thicknesses are based on the geology of the 100 N and 100 H areas. The information below is from Lindsey and Jaeger (1993), who have recently described the geology of this area. Figures 4.2-23 and 4.2-24 show cross sections of the northern portion of the Hanford Site including both 100 D and 100 H areas. Up to 30 m (100 ft) of Lower Mud Sequence muds and sands are thought to be present above the basalt. Overlying the Lower Mud Sequence are 61 m (200 ft) of fine-grained overbank/paleosol sediments. Erosion before and possibly during cataclysmic flooding has eroded much of the uppermost Ringold sediments in the 100 D Area, leaving gravel and sand of the Ringold Unit E only in the southern and western portions of the area. In the northern and



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Figure 4.2-22. Cross section through the 100 B/C Area (modified from Lindsey 1993a).

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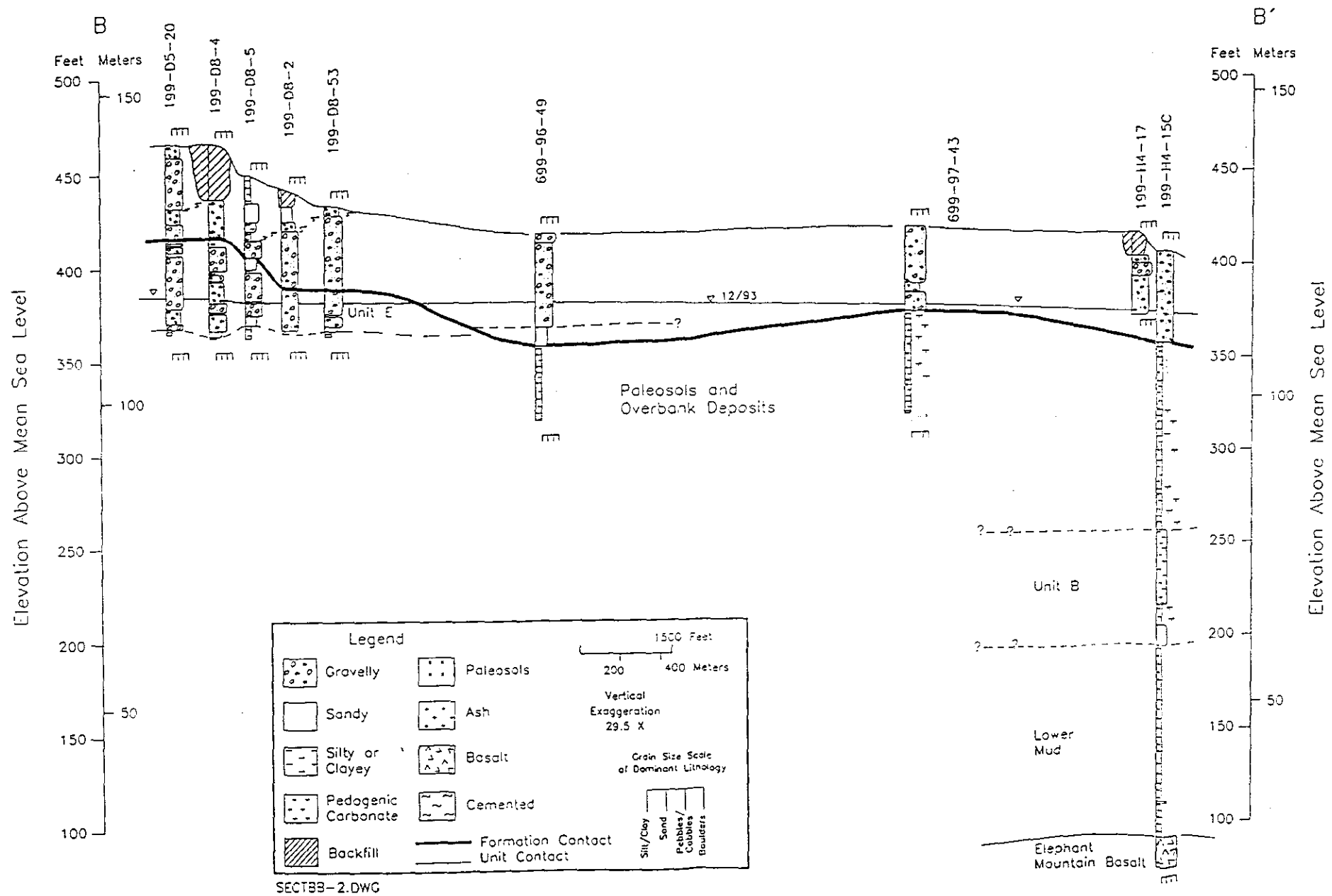


Figure 4.2-23. Cross section B-B' through the 100 D and 100 H Areas (modified from Lindsey and Jaeger 1993).

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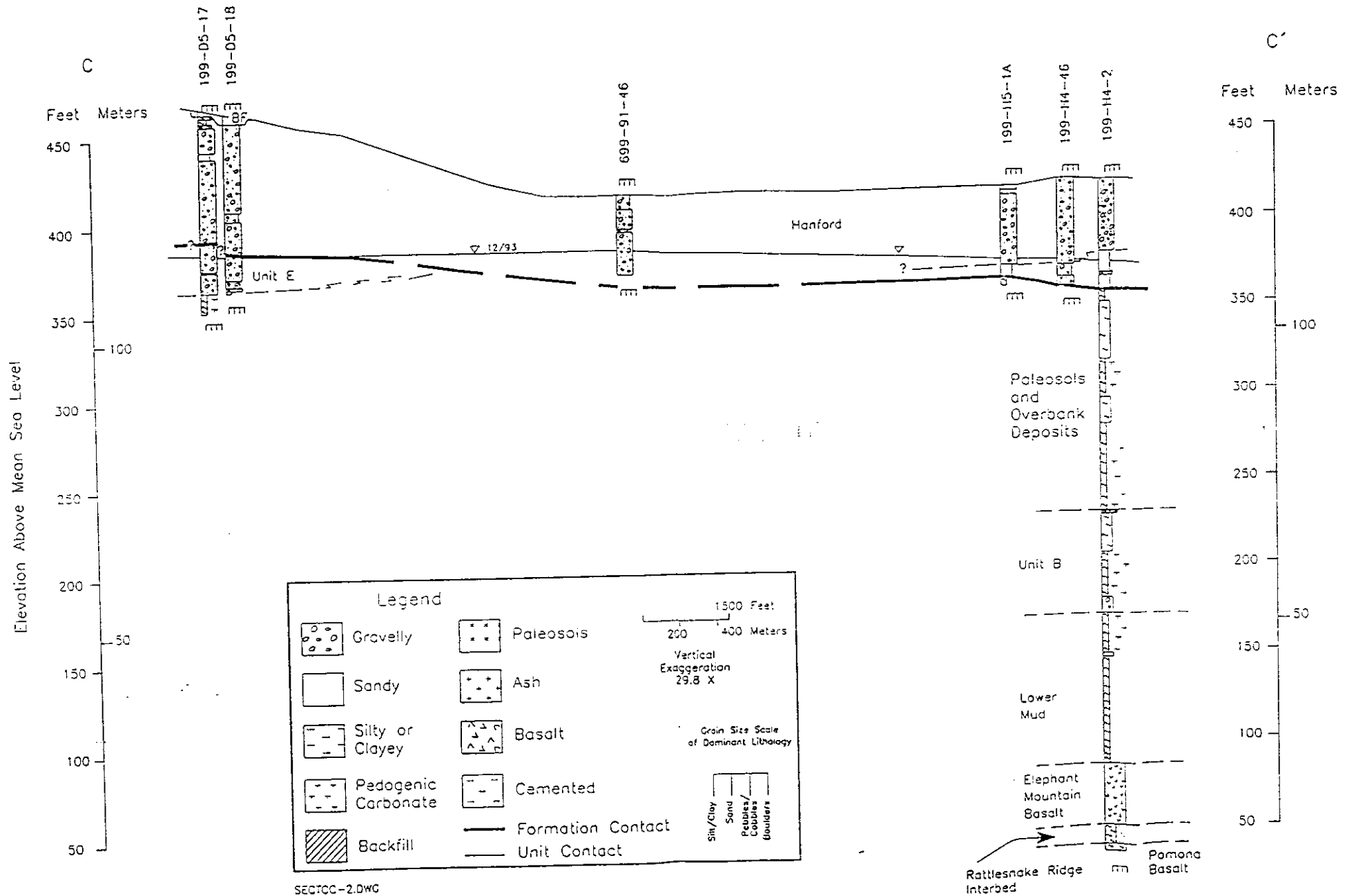


Figure 4.2-24. Cross section C-C' through the 100 D and 100 H Areas.

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eastern portions, the Hanford formation rests directly on the overbank/paleosol sediments. Throughout the area, the Hanford Formation consists of the sand-dominated and Pasco Gravels facies. The upper half of the Hanford is characterized by the alternation of these two facies, while the lower half consists of the Pasco Gravels facies.

Immediately adjacent to the Columbia River are localized recent river deposits. In some areas, overbank deposits can also be found filling abandoned or intermittently active river channels. Windblown sand forms a thin, discontinuous layer across the 100 D Area. In some areas the Hanford formation has been excavated, and the area filled with backfill consists primarily of power-plant fly ash. Near the 100 D Ponds, all (20 m) 65 ft of the Hanford formation has been removed and partially replaced by backfill. The water table in the 100 D Area lies in the near the Ringold/Hanford contact, but is generally within the gravels and sands of Ringold Unit E.

100 F Area. In the vicinity of the 100 F Area, the top of basalt is approximately 107 m (350 ft) below ground surface. Overlying this is approximately 30 m (100 ft) of fine-grained mud and sand of the Ringold Lower Mud Sequence. A cross section through the 100 F Area is provided in Figure 4.2-25. Roughly 20 m (65 ft) of gravel and sand comprising Ringold Unit B overlie the Lower Mud Sequence, followed by 61-70 m (200-230 ft) of mud and sand forming a sequence of paleosols and overbank deposits (Lindsey 1992). There are no gravels corresponding to Ringold Units A or E in the 100 F Area.

Overlying the Ringold is approximately 9 m (30 ft) of Hanford Formation sediments dominated by granule- to cobble-gravel. Recent river deposits can be found immediately adjacent to the river. Eolian deposits are relatively common in the vicinity of the 100 F Area, forming sand dunes in places. The water table lies within the uppermost portion of the Ringold overbank/paleosol sequence in this area.

100 H Area. The top of basalt in the 100 H Area is approximately 93 m (305 ft) below ground. Lindsey and Jaeger (1993) have recently described the geology of this area, and much of the following information is from their report. See Figures 4.2-23 through 4.2-24 for cross sections showing the general relationship of the geologic units in this area. Overlying the basalt in this area is 26-30 m (85-100 ft) of Ringold Lower Mud Sequence mud, which is overlain by up to 23 m (75 ft) of overbank/paleosol muds containing sandy interbeds thought to correlate to Ringold Unit B. Above these sandier sediments is another 30-38 m (100-125 ft) thick sequence of mud-rich overbank/paleosol sediments which form the top of the Ringold in the 100 H Area.

The Hanford formation in the 100 H Area consists of Pasco Gravels facies sediments, ranging from 10 to 19 m (32 to 63 ft) thick. Near the Columbia River and in abandoned and intermittently active channels occur river and overbank deposits. In addition, a thin layer of windblown sand covers much of the area. Backfill is also present in varying amounts, with most located in the vicinity of large construction sites. The water table in the 100 H Area occurs in the lower portion of the Hanford formation.

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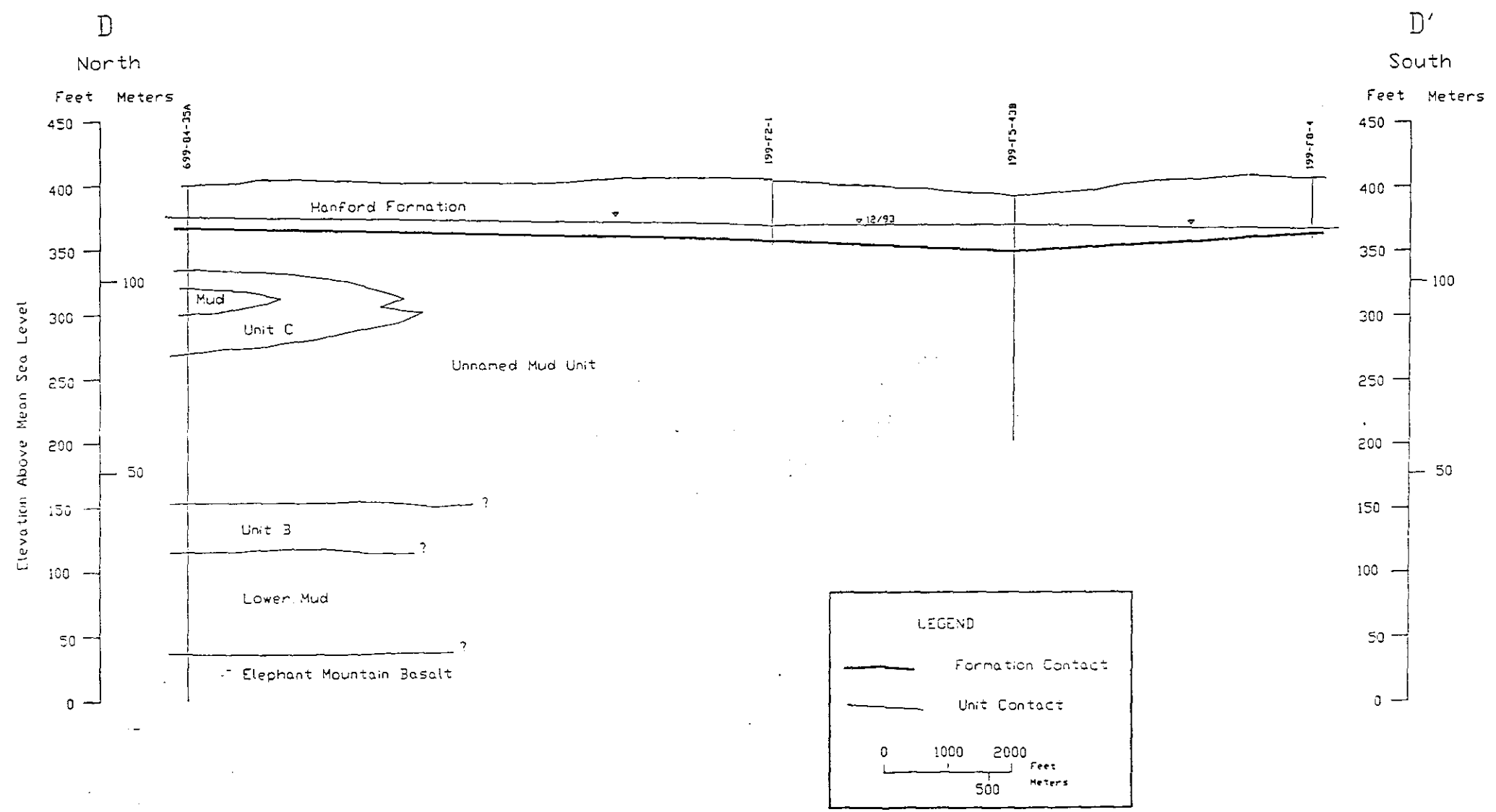


Figure 4.2-25. Cross section through the 100 F Area.

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100 K Area. Lindberg (1993b) discusses the geology of this area in detail, and most of the following information is from that report. Figure 4.2-26 shows a cross section of this area. Depth to basalt in the 100 K Area is approximately 162 m (530 ft). Only one borehole penetrated all of the suprabasalt sediments, and the thicknesses of the lower Ringold units are consequently based on that one borehole. Lying atop the basalt is 7 m (23 ft) of fluvial gravel and sand of Ringold Unit A. Approximately 32 m (105 ft) of Lower Mud Sequence muds and occasional sand overlie Unit A. In the 100 K Area, the overlying Unit B is 27 m (90 ft) thick and consists of mostly sand. Overlying Unit B is 31 m (103 ft) of overbank/paleosol mud, followed by 3 m (10 ft) of gravel and 29 m (95 ft) of overbank/paleosol mud in ascending order. This uppermost Ringold mud is overlain by Ringold Unit E, which is 19-41 m (64-136 ft) thick, depending on the amount of erosion on its surface.

Thickness of the Hanford Formation ranges from 0 to 40 m (0 to 130 ft) thick, thinning near the Columbia River (Lindberg 1993b) and thickest on the southeast side of the 100 K Area. Hanford Formation sediments are represented by the Pasco Gravels facies, with occasional sand-dominated lenses occurring locally. Boulders are common in the upper 6-15 m (20-50 ft).

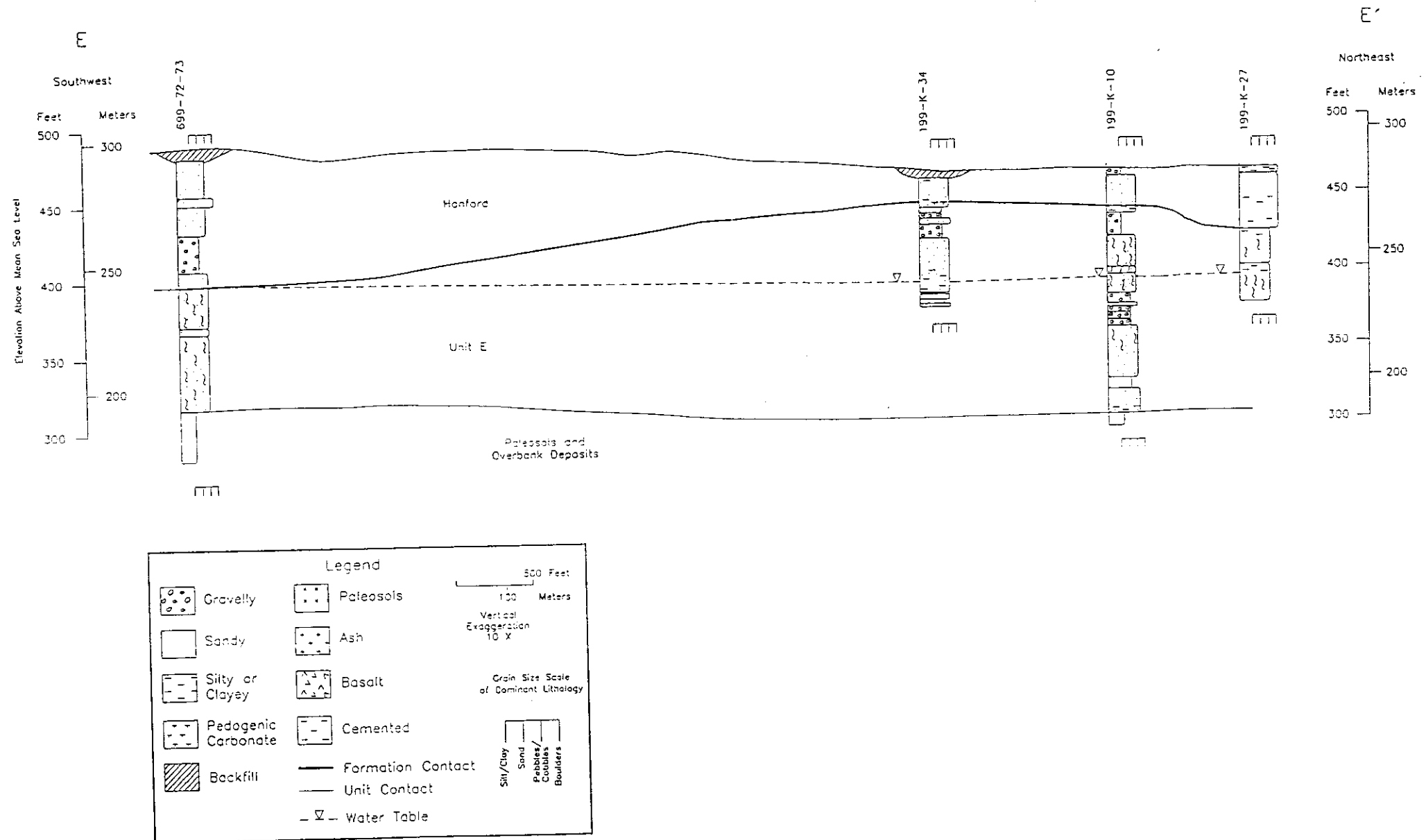
Recent river and overbank deposits can be found near the Columbia River. Eolian deposits are very thin and discontinuous. Excavations for construction projects in the 100 K Area have been backfilled with local sediments, usually Hanford formation or Ringold Unit E material. The water table in this area occurs within the Ringold Unit E.

100 N Area. The top of basalt is approximately 125 m (410 ft) in depth in the 100 N Area. Hartman and Lindsey (1993) has described the hydrogeology of this area; much of the following information is from that report. A cross section is provided in Figure 4.2-27. Ringold Unit A overlies the basalt, forming a 4-8 m (12-25) ft thick layer of fluvial sand and gravel which pinches out to the north. The Lower Mud Sequence is approximately 30 m (100 ft) thick and is overlain by Unit B, which consists of approximately 21 m (70 ft) of mostly sand with minor gravel. Unit B is overlain by almost 43 m (140 ft) of overbank/paleosol mud and sand, Unit C consisting of 3 to 5 m (10 to 15 ft) of sand and gravel, and up to 30 m (100 ft) of overbank/paleosol mud and sand. The uppermost Ringold unit in the 100 N Area is Unit E, which ranges from 5 to 20 m (17 to 65 ft) thick, with the surface irregularly eroded before and during cataclysmic flooding.

Hydrology

In the 100 Areas, which border the southern and southeastern shore of the Columbia River along the Hanford Reach, the water table ranges in depth from 30 m (107 ft) to 10 m (33 ft), and the groundwater flow direction is generally perpendicular to the river. This is the only undammed section of the Columbia River, but the river levels and stages are still controlled by dams upstream. Typically, the groundwater flow direction is towards the river. However, during river stages when the river level is above the groundwater table, the flow is reversed.

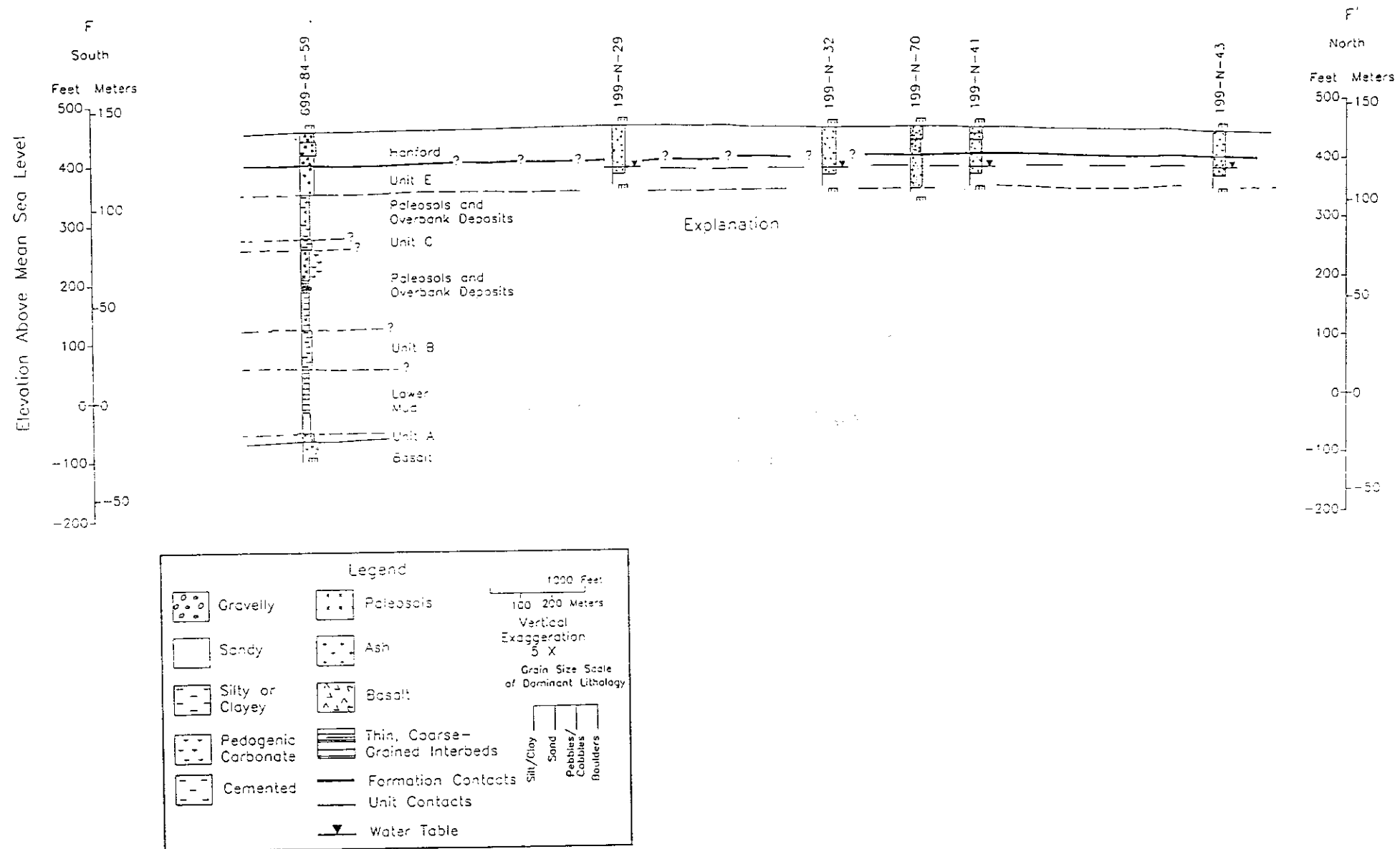
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Figure 4.2-26. Cross section through the 100 K Area (modified from Lindberg 1993b).

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Figure 4.2-27. Cross section through the 100 N Area (modified from Hartman and Lindsey 1993).

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Both before and during Hanford Site operations, the Columbia River has been a "gaining" stream because the groundwater ultimately discharges into the river. Most of this discharge occurs underwater, and only at low river levels does groundwater seepage occur where it can be observed. During high river stages, the river flows into the riverbank and either mixes with the groundwater or overlies it. As the river stage lowers, both the river water and groundwater stored in the riverbank flow back into the Columbia (Newcomb and Brown 1961).

Along the 100 Areas shoreline, daily river level fluctuations may result in an elevation change of 1.8-2.4 m (6-8 ft), and seasonal fluctuations may be in the 2.4-3 m (8-10 ft) range. As the river stage rises, a pressure wave is transmitted inland through the groundwater. The longer the duration of the higher river stages, the further inland is the effect propagated. The pressure wave is observed farther inland than the water actually goes. For the river water to flow inland, the river level must be higher than the groundwater surface, and must remain high for a long enough time for the water to flow through the sediments. Typically, this inland flow of river water is restricted to within several hundred feet of the shoreline (McMahon and Peterson 1992).

Hydraulic conductivities based on measurements in the 100 N Area, suggest two regimes. Gilmore et al. (1992) found hydraulic conductivities from approximately 11-66 m/day (36-215 ft/day) and 99-185 m (325-606 ft/day). Earlier test results (Biershenk 1959) determined hydraulic conductivity of the Hanford sediments to range from 396 to 2440 m/day (1300 to >8000 ft/day), and Ringold units to range from 3 to 24 m (10 to 80 ft/day). Thorne and Newcomer (1992) present a summary and analysis of available hydraulic data for the Hanford Site unconfined aquifer system in which 100 H Area conductivities are listed as ranging from 22 to 1812 m/day (71 to 5940 ft/day) based on Liikala et al. (1988).

The geology of the water table is shown in Figure 4.2-28 (from Lindsey 1992). Six hydrogeologic units are found in the western 100 Areas: the unsaturated (vadose) zone, the Ringold/Hanford producing layer, the Ringold confining layer, the Ringold semi-confined aquifer, another Ringold confining layer, and a Ringold semi-confined aquifer. In the 100 D, 100 F, and 100 H Areas, sediments are increasingly fine-grained, and groundwater is either in the Hanford formation or from thin permeable zones within the thick mud layers (see Figures 4.2-23, 4.2-24, and 4.2-25)

The unsaturated (vadose) zone in the 100 Areas is contained primarily within the Hanford formation and ranges in thickness between 3 and 24 m (10 and 80 ft) in the vicinity of the river, and approaches 40 m (130 ft) in the central area north of Gable Mountain. These relatively high conductivity sediments typically are open-framework pebble to boulder-sized gravels. Interstitial sand content is generally low, and mud-sized sediment is limited to coatings on individual grains and rip-up clasts. Interstratified lenses of sand and mud are very localized. Perched water has been encountered once at 100 N in 1984.

Figure 4.2-28. Geologic units intersected by the water table in the 100 Areas (modified from Lindsey 1992).

In the western portion of the 100 Areas, the water table and uppermost saturated unit typically occur in the fluvial sediments of Ringold gravel unit E, however, there may be locations at which the lowest few feet of the Hanford sediments are also saturated (see Figures 4.2-22, 4.2-26, and 4.2-27). Channels and other erosional features reflect the unconformity between the Hanford and Ringold sediments; and where they are filled with the more permeable Hanford deposits, the "buried" channels may act as preferred pathways for groundwater movement. In the region around the 100 H and F Areas, Ringold gravel unit E is absent and the uppermost saturated unit consists entirely of Hanford gravels (see Figures 4.2-23, 4.2-24, and 4.2-25). Liikala et al. (1988) reported transmissivities from 90 to 4770 m²/day (1,000 to 53,000 ft²/day) and hydraulic conductivities from 6 to 540 m²/day (70 to 6,000 ft²/day) for 100 H Area wells.

The next hydrogeologic unit is a confining interval (aquitard) that consists of interbedded clays, silts, and thin, random sand lenses. These are overbank deposits, and this interval ranges in thickness from 3 to 15 m (10 to 50 ft) and is continuous across the 100 Areas.

The fourth hydrogeologic unit is a semi-confined aquifer 53-61 m (175-200 ft) thick, composed of Unit B and/or Unit C, which are primarily silty sand and sandy silt layers. These lithologies alternate within the unit and suggest that this "semi-confined" unit actually consists of alternating producing and confining layers. This hydrostratigraphic unit is coarser toward near 100 K and 100 B/C Areas, and fines toward the 100 H and F Areas.

The next hydrostratigraphic unit is a confining layer 30.5-47 m (100-150 ft) thick, consisting of interbedded clay and silt. This geologic unit has been assigned to the lower mud sequence of the Ringold Formation (Section 4.2.2). These fine-grained sediments, which are predominantly lacustrine, are continuous across the 100 Areas.

The lowest hydrogeologic unit within the unconfined aquifer is equivalent to Ringold gravel unit A, which consists of interbedded sands and pebble- to cobble-sized gravels, with occasional caliche layers, and ranging in thickness from 5 to 20 m (18 to 65 ft). Unit A does not appear to be present at 100 F, H or D Areas (Lindsey et al. 1992). This unit lies unconformably over the Elephant Mountain Basalt.

The Elephant Mountain Basalt member of the Columbia River Basalt Group is found throughout the 100 Areas. It contains vesicular zones, but is also >30 m (100 ft) thick and lies above the uppermost confined aquifer, i.e., the Rattlesnake Ridge interbed and Pomona flowtop zone. Therefore, vertical flow to that interbed is highly unlikely.

4.2.4 200 Areas Geology and Hydrology

Geology

The geology in the 200 West and 200 East areas is surprisingly different, although they are separated by a distance of only 6 km (4 mi). One of the most complete suprabasalt stratigraphic sections found on the Hanford Site is in 200 West. Almost all the Ringold Formation units identified by Lindsey (1991a) are found in 200 West Area, along with the

Plio-Pleistocene unit, early "Palouse" soil, and the Hanford Formation. In 200 East Area, all the Ringold Formation has been eroded in places, with complex relationships between the Hanford and remnants of Ringold formations in other parts. Because of the differences, each area will be discussed separately below.

200 West Area. The 200 West Area is located above the southward-dipping north limb of the Cold Creek syncline, whose axis is located between 1 and 4 km (0.5 and 2.5 mi) to the south (Figure 4.2-29). The uppermost basalt unit is the Elephant Mountain flow, which is continuous across the area. Depth to the top of basalt ranges from approximately 137 m (450 ft) in the north to 183 m (600 ft) in the south (Lindsey 1991b). Most Ringold Formation sediments were deposited during subsidence of the Cold Creek syncline, causing thicker accumulations of sediments near the synclinal axis and little or no deposition closer to the anticlinal axis. Ringold Formation Unit A, which overlies the basalt in the 200 West Area, is a good example of this. Its thickness ranges from 0 m on the northern side of 200 West Area to 38 m (125 ft) on the southern side closest to the Cold Creek syncline axis. The top of this unit also reflects continuing subsidence of the basalt after deposition of Unit A, with the top of unit elevations at nearly 91 m (300 ft) above sea level in the northeastern corner, and less than 46 m (150 ft) above sea level in the southwestern corner. Unit A consists of fluvial gravels and sands, and is overlain by the lacustrine mud and overbank/paleosol sand and mud of the Lower Mud Sequence. The Lower Mud ranges in thickness from 0 m in the northeastern corner of 200 West Area to >38 m (125 ft) in the southwestern corner. The surface of the Lower Mud Sequence is irregular, indicating erosion after deposition (Lindsey 1991b).

Units B, C, and D and the interfingering unnamed muds have not been identified in the 200 West Area, either because the unnamed muds have been eroded and the coarse-grained units cannot be distinguished from fluvial gravels of Unit E, or because they were not deposited in this area. In either case, Lindsey (1991b) has interpreted the thick fluvial gravel sequence overlying the Lower Mud as Ringold Unit E. In the northeastern corner of the area, Unit E lies directly on Unit A, with no interlayered mud. Above Unit E in the west, north, and central parts of 200 West are the sand and mud of the Upper Ringold Unit. In other parts of the area, this unit has been eroded. On the eroded surface the Plio-Pleistocene unit developed and consists of primarily carbonate-rich strata with some predominantly basaltic gravel sidestream deposits, and is 0 to >12 m (40 ft) thick across the 200 West Area (Bjornstad 1984; Lindsey 1991b). The eastern extent of the Plio-Pleistocene unit occurs near the eastern boundary of the 200 West Area. Windblown loess-like sediments of the early "Palouse" soil form an irregular blanket over the Plio-Pleistocene unit, ranging in thickness from 0 m in the northwestern corner to 12-15 m (40-50 ft) on the south side of the 200 West Area. This unit is being reevaluated, however, and in places the upper portions may be included with the fine-grained Hanford Formation which overlies it.

Cataclysmic flooding created the flood bar on which the 200 West Area lies. Umtanum Ridge partially protected the bar from the erosive force of the floodwaters, leaving a thicker sequence of Ringold sediments and allowing deposition of a relatively thick sequence of Hanford Formation sediments. In the 200 West Area, both Pasco Gravels and sand-

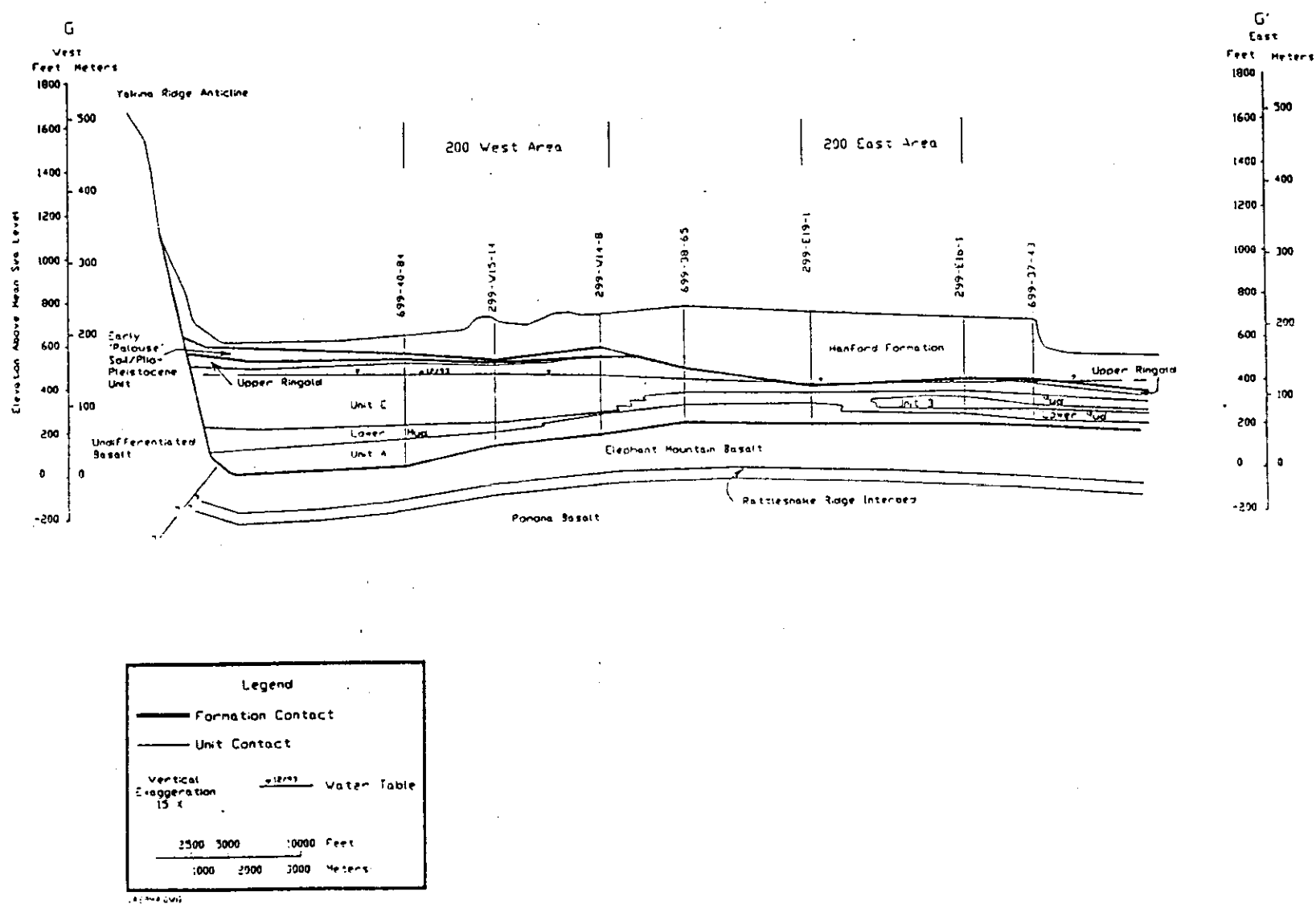


Figure 4.2-29. Cross section through the 200 West and 200 East Areas.

dominated facies of the Hanford formation are present. The sand-dominated facies sediments overlie the early "Palouse" soil in the eastern, western, and southern portions of 200 West with thicknesses ranging from 0 to >46 m (150 ft) thick on the south side. This fine-grained unit does not occur in the northern and central portions. The Pasco Gravel facies lies directly on the Plio-Pleistocene unit in the northern part of 200 West; elsewhere it lies on the sand-dominated facies of the Hanford formation. It is >61 m (200 ft) thick in the northwestern portion of 200 West, and nonexistent in the southern part where the sand-dominated facies is the only Hanford unit deposited. On the surface of 200 West is a thin, discontinuous layer of windblown sand, where it has not been removed by construction activities. The water table in the 200 West Area usually occurs in Unit E of the Ringold Formation.

200 East Area. The 200 East Area as it is discussed here includes the area within the 200 East Area fence as well as the associated waste-disposal facilities to the south and the B-Pond complex to the east. The 200 East Area is located on the southward-dipping northern limb of the Cold Creek syncline, with the basalt surface dipping gently to the south-southwest toward the axis of the syncline (Figure 4.2-29). The Elephant Mountain basalt forms the uppermost basalt unit over most of the area, although it has been eroded to varying extent and is absent in several boreholes just north of the 200 East Area. Where the Elephant Mountain basalt has been eroded, the normally confined Rattlesnake Ridge Interbed is in direct communication with the unconfined aquifer. The top of basalt in the vicinity of 200 East is not smooth, with small anticlines located between the northern boundary and Gable Mountain. Subsidence of the Cold Creek syncline was still occurring during deposition of the older Ringold sediments, and the surfaces of most of them reflect this by lower elevations and increased thicknesses toward the synclinal axis.

Overlying the basalt in the central and southern portions of 200 East are the fluvial sands and gravels of Ringold Unit A (Lindsey et al. 1992). This unit varies in thickness from 0 to >30 m (100 ft) thick in the central and southeastern parts. Unit A has probably been eroded from the northern part of the area. The Lower Mud Sequence of lacustrine mud and overbank/paleosol sand and mud lies above Unit A in most areas, and directly overlies basalt in some areas north of 200 East where Unit A is missing. The northern boundary of the Lower Mud occurs in an irregular pattern over the southern and east-central parts of 200 East, reflecting erosion before and during cataclysmic flooding. Thickness ranges from 0 m in the north and central areas to 18 m (60 ft) on the south. Units B, C, and D and the interlayered unnamed muds are not found clearly identified in the 200 East Area. Consequently, Unit E overlies the Lower Mud Sequence in the south and east-central portions of 200 East, ranging in thickness from 0 in the north to 100 ft in the south. There are no Upper Ringold unit, Plio-Pleistocene unit, or early "Palouse" soil sediments found in the 200 East Area. Altogether, some unit of the Ringold Formation covers the southern two-thirds of the 200 East Area, with Unit A occurring furthest north, and Unit E generally occurring furthest south.

The Hanford formation sediments can be broken into three units in 200 East; the lower gravel, middle sand, and upper gravel units. The lower and upper gravel units consist of Pasco Gravels facies sediments, with an intervening sand-dominated facies sequence (Lindsey et al. 1992). The lower gravel unit ranges from 0 to 40 m (130 ft) thick, with the

thickest areas on the southwest and east sides, and a large "window" in the central 200 East Area. The overlying sand-dominated unit ranges in thickness from approximately 25 to nearly 92 m (300 ft), with the thickest accumulation where the "window" in the underlying gravel unit occurred. In the northern part, this unit consists of coarse sand which becomes finer-grained to the south with increasing interfingerings of slackwater type sediments. The upper gravel unit is very similar to the lower unit; where the sand unit is missing, they have been grouped together. The upper gravel is thickest in the northern part of 200 East, thinning and being replaced by the sand unit to the south. It is up to 30 m (100 ft) thick in the northeastern corner of 200 East, where a flood channel was apparently located. The water table in the 200 East Area is usually found in the Hanford formation.

Hydrology

Although their proximity would suggest that the 200 East and West subsurface hydrology would be quite similar, in fact the 200 East Area is closer to the center of the Pleistocene flood channels. Consequently, the hydrology is quite different beneath the 200 East and West Areas. That the elevation of the water table beneath the 200 Areas is declining is primarily attributed to an overall decrease in wastewater discharged to various cribs, trenches, and ponds in the 200 Areas, and to the continued dissipation of the groundwater mound under U Pond since its decommissioning in 1984 (Newcomer et al. 1992).

200 West Area. The sediments of the Hanford formation, the early "Palouse" soil, Plio-Pleistocene unit, as well as some Ringold sediments, compose the vadose zone. The water table in 200 West Area is generally in Ringold Unit E (Figure 4.2-29). During operations at the Hanford Site, the major high-volume water disposal site for the 200 West Area was U-Pond, where the water table rose approximately 20 m (65 ft). The artificially-produced mound that formed under U-Pond altered local groundwater flow directions, from the previous west-to-east flow to a radial outward flow. U Pond was deactivated in 1984, at the same time that the maximum elevation of the groundwater mound occurred at approximately 148 m (485 ft) above mean sea level. The water level in one well decreased approximately 5.12 m (16.8 ft) between June 1984 and June 1991 (Newcomer et al. 1992).

Because of the locally finer-grained constituents of the Ringold and Hanford formations, conductivity measurements are quite low. Conductivity ranges from .048 to 61 m/day (0.16 to 200 ft/day) have been reported in Thorne and Newcomer (1992), based on reports by Last et al. (1989) and Kipp and Mudd (1973). The mound remains ten years after U-Pond decommissioning, but the watertable elevation is declining as the unconfined aquifer reequilibrates to a more natural recharge regime following reduction of the artificial recharge.

Confined aquifer units occur within the lower Ringold Formation. Confining conditions result from fined-grained matrices with a range in amount of silt and clay and degree of cementation. The Lower Mud unit occurs throughout the 200 West Area, and dips and thickens towards the southwest. The Lower Mud near U-Pond was found to have a

hydraulic conductivity of 2.7 m/day (9 ft/day) (Graham et al. 1981). Earlier work by Newcomb et al. (1972) determined a hydraulic conductivity of 4.3 m/day (14 ft/day).

200 East Area. In general, the uppermost aquifer system within the 200 East groundwater aggregate area (including operations outside of the 200 East boundary related to 200 East operations, e.g., B Ponds) includes the saturated units above the uppermost basalt surface (Delaney et al. 1991). Where erosion from cataclysmic flooding has removed the Elephant Mountain Member of the Saddle Mountain Basalt Formation, stratigraphically lower basalts are the base of the uppermost aquifer system. This erosional surface has created localized communication between the unconfined aquifer and the confined aquifers in the underlying basalt interbeds (Graham et al. 1981).

The disposal of large volumes of water to B Pond has altered the regional ground flow direction locally as a result of the artificial groundwater mound that now exists beneath B Pond (Newcomer 1990), although the water table is declining as a result of reduced operations (Newcomer 1990; DOE 1992a,b). Groundwater flow is radially outward from B Pond, generally to the north in the area north of 200 East, from west to east in the area between 200 East and 200 West, and generally from west to east (and southeast) south of the 200 East Area. Within the 200 East Area, an extremely flat horizontal gradient (0.0001 to 0.0002) prevents a definitive groundwater flow direction from being measured, although it is most probable that the regional flow direction from west to east predominates over most of the area. Connelly et al. (1992) described a hydrogeologic model for the 200 East Area and provide a series of three-dimensional figures illustrating locations of the saturated units through the geologic section.

In descending order, the hydrogeologic units include sands and gravels of the Hanford formation, fluvial gravel units of the Ringold Formation, and sands of the Rattlesnake Ridge interbed of the Ellensburg Formation. The water table in 200 East Area is generally in Hanford formation sediments in the north and Ringold Unit E in the south (Figure 4.2-29). Semiconfined to confined conditions occur beneath the fine-grained Lower Mud unit of the Ringold Formation. Graham et al. (1984) noted that the Ringold Formation Lower Mud unit appears to act as an aquitard in the southwest portion of the 200 East Area. The Lower Mud unit also acts as a confining unit in the B Pond vicinity, over Ringold Unit A according to Davis and Delaney (1992). Thus, where the Ringold Lower Mud unit is present above unit A, unit A is considered to be a semiconfined to confined aquifer. The Lower Mud unit pinches out to the west and north of B Pond and thickens to the southeast (Davis and Delaney 1992).

A number of aquifer tests have been conducted to determine hydraulic conductivities and transmissivities for the hydrogeologic units in the 200-East aggregate area. These tests are described in Newcomer et al. (1992), Swanson et al. (1992), Kasza et al. (1991) and Jackson (1992). Conductivities in the upper, transmissive aquifer (above the Lower Mud unit) range from 73 to 1524 m/day (240 to 5000 ft/day) (Last et al. 1989; Graham et al. 1981, 1984).

Vertical downward gradients exist in the uppermost aquifer near B Pond, based on data from wells completed at different intervals (Connelly et al. 1992). The existence of vertical

gradients along with erosion features in the 200 East Area creates the possibility of aquifer communication, whereby groundwaters from distinct hydrogeologic systems intermingle and mix. In fact, groundwater does flow from the uppermost aquifer system into the Rattlesnake Ridge aquifer system, in the vicinity of B Ponds (Jensen 1987). Graham et al. (1984) determined that there is an "erosional window" into the confined basalt aquifer system located north of the 200 East Area, and either a second window or well-developed fracture system in the northeast corner of the 200 East Area, which appear to allow aquifer communication. The existence of the erosional window and significant joint and fracture systems in the Elephant Mountain basalt member and of engineered intrusions (i.e., ground-water well construction) allows downward-directed vertical hydraulic gradients or gravity-driven density plume migration. Downward vertical hydraulic gradients have existed in the past throughout most of the 200 East Area because of large-scale liquid waste-water disposal. High-salt wastes with densities > 1.0 are also known to have been disposed to various wastewater facilities in the 200 East Area (Smith 1980; Graham et al. 1984). Currently, the potential for vertical flow based on hydraulic heads in the unconfined and confined aquifers in the area suggests an upward direction elsewhere other than B Pond (Jensen 1987).

Past operations, including quantities of wastewater disposed to both ground and high-salt wastes, have contributed to the process of aquifer communication. Based on current geologic, hydrologic and groundwater quality data, areas of aquifer communication currently appear to be limited to the vicinity of B Pond (Connelly et al. 1992).

4.2.5 300 Area Geology and Hydrology

Geology

The 300 Area is located on the southeastern portion of the Hanford Site and is bordered by the western shore of the Columbia River along the southern stretch of the Hanford Reach. The 300 Area lies above a gentle syncline formed by the intersection of the Palouse slope and the western side of the Pasco Basin. Depth to basalt is roughly 61 m (200 ft) below ground. Over most of the Hanford Site, the uppermost basalt unit is the Elephant Mountain Member. In the southern portion of the Hanford Site, however, the younger Ice Harbor Member flows are found. Beneath the 300 Area, the Martindale flow of the Ice Harbor Member forms the top of basalt. Just north of the 300 Area, the younger Goose Island flow lies above the Martindale, causing a relative high in the top of basalt surface (Schalla et al. 1988).

Swanson (1992) indicates Ringold Unit A occurs as a thin, discontinuous layer (Figure 4.2-30) in the 300 Area. Consequently, the Lower Mud Sequence often lies directly on top of the basalt. The lacustrine muds and overbank/paleosol sand and mud of this unit cover the entire 300 Area. It ranges from 2 to 24 m (8 to 80 ft) thick, thinning to the north across the Goose Island basalt high, and thickening to south. Overlying the Lower Mud Sequence is a complex series of fluvial gravels with interfingering mud layers. This sequence is correlated at least in part to Ringold Unit E, because it is at approximately the same elevation as outcrops of Unit E in the White Bluffs across the river. Thickness ranges from 0 to nearly 12 m (40 ft) in the vicinity of the 300 Area. A channel has been cut

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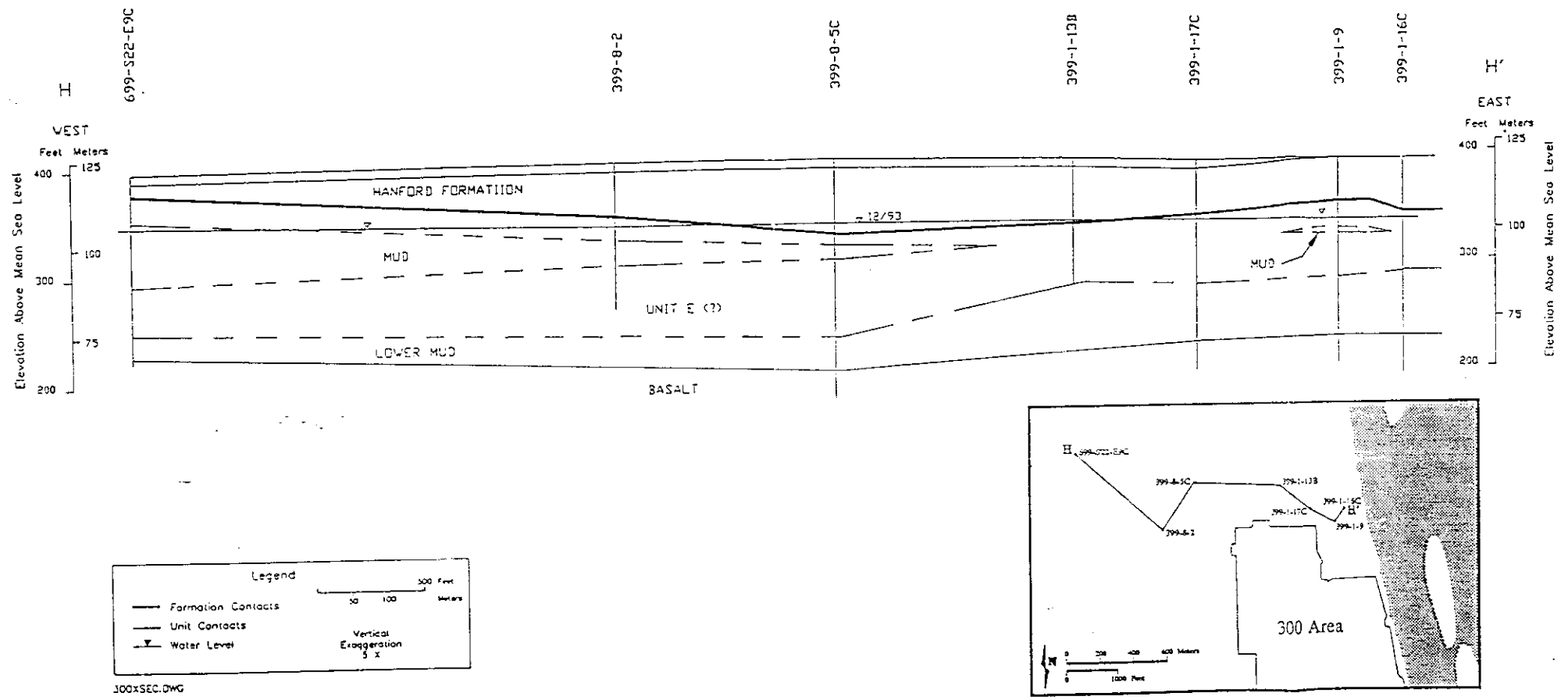


Figure 4.2-30. Cross section through the 300 Area (modified from Swanson 1992).

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through these sediments in a loop from the Columbia River west beneath the 300 Area and back to the Columbia River shore (Swanson 1992). There is no Upper Ringold unit present, having been eroded prior to or during cataclysmic flooding. The Plio-Pleistocene unit and early "Palouse" soil are also missing in the 300 Area.

The Hanford formation in the 300 Area is primarily represented by Pasco Gravels facies with a significant proportion of boulders. In some places, relatively thick lenses of sand-dominated facies occur, but do not appear to be laterally extensive (Swanson 1992). The Hanford formation ranges from 9 to 18 m (30 to 60 ft) thick, in general thickening toward the river. The water table in the 300 Area can fluctuate dramatically due to changing river levels. However, the water table is generally in the uppermost Ringold unit.

Hydrology

The unconfined aquifer in the vicinity of the 300 Area is relatively shallow with either the Lower Mud Ringold unit, which acts as a confining layer, and/or the basalt bedrock 53 m (174 ft) below land surface in the vicinity of the process trenches (Figure 4.2-30). Depths to water table range from about 9 to 19 m (30 to 62 ft) below land surface. River stages, which can affect the direction of groundwater flow, are controlled by dams on the Columbia and Snake Rivers (Campbell 1994). As in the 100 Areas, groundwater flow direction is complex. When the river level is below the water table elevation, groundwater flow is towards the river with perpendicular, downstream, and downward vertical-flow components. When the river stage is higher for prolonged periods of time, the localized flow direction is inland. Except for high river stage reversals, the general groundwater flow direction is predominantly to the southwest. In fact, water table contours suggest that groundwater flows from the northwest, west, and southwest to discharge into the Columbia River in the vicinity of the 300 Area.

Schalla et al. (1988) reported hydraulic conductivities in the unconfined aquifer to range from 150 to 15,240 m/day (500 to 50,000 ft/day). High hydraulic conductivities explain why, in spite of large wastewater discharges to the Process Trenches at the north of the 300 Area, there has been no mounding of the groundwater in this area.

1100 and 3000 Areas

The groundwater in the southeastern portion of the Hanford Site is less impacted by Hanford Site operations than by other activities. In addition to natural recharge, artificial recharge is associated with the North Richland recharge basins (used to store Columbia River water for Richland water use) south of the 1100 Area, and irrigated farming in the 3000 Area and west and southwest of the 1100 Area. Although pumping to obtain water also occurs from the unconfined aquifer in these areas, there is a mound in the water table beneath the Richland city system of recharge basins. The Richland city recharge basins are used primarily as a backup system between January and March each year when the filtration plant is closed for maintenance, and during the summer months to augment the city's river-water supply. The water level also rose from December 1990 and December 1991 in the area of the Lamb-Weston Potato-Processing Plant, which uses large amounts

of water and, except for plant maintenance during the month of July, operates year-round. The water table in the 1100 Area seems to reflect irrigation cycles connected with agriculture and the growing season (Newcomer et al. 1992).

4.3 Ecology

The Hanford Site is a relatively undisturbed area (1450 km², ~560 mi²) of shrub-steppe that contains numerous plant and animal species adapted to the region's semiarid environment. The site consists of mostly undeveloped land with widely spaced clusters of industrial buildings located along the western shoreline of the Columbia River and at several locations in the interior of the site. The industrial buildings are interconnected by roads, railroads, and electrical transmission lines. The major facilities and activities occupy about 6% of the total available land area, and their impact on the surrounding ecosystems is minimal. Most of the Hanford Site has not experienced tillage or livestock grazing since the early 1940s. The Columbia River flows through the Hanford Site, and although the river flow is not directly impeded by artificial dams within the Hanford Site, the historical daily and seasonal water fluctuations have been changed by dams upstream and downstream of the site (Rickard and Watson 1985). The Columbia River and other water bodies on the Hanford Site provide habitat for aquatic organisms. These habitats are discussed in detail in Subsection 4.3.2. The Columbia River is also accessible for public recreational use and commercial navigation. Other descriptions of the ecology of the Hanford Site can be found in ERDA (1975), Rogers and Rickard (1977), Jamison (1982), Watson et al. (1984), Sackschewsky et al. (1992), Weiss and Mitchell (1992), Downs et al. (1993), and Cadwell (1994).

4.3.1 Terrestrial Ecology

Vegetation

The Hanford Site, located in southeastern Washington, has been botanically characterized as a shrub-steppe (Daubenmire 1970). Because of the aridity, the productivity of both plants and animals is relatively low compared with other natural communities. In the early 1800s, the dominant plant in the area was big sagebrush with an understory of perennial bunchgrasses, especially Sandberg's bluegrass and bluebunch wheatgrass. With the advent of settlement that brought livestock grazing and crop raising, the natural vegetation mosaic was opened to a persistent invasion by alien annuals, especially cheatgrass. Today cheatgrass is the dominant plant on fields that were cultivated 40 years ago. Cheatgrass is also well established on rangelands at elevations < 244 m (800 ft) (Rickard and Rogers 1983). Wildfires in the area are common; the most recent extensive fire in 1984 significantly altered the shrub component of the vegetation. The dryland areas of the Hanford Site were treeless in the years before land settlement; however, for several decades before 1943, trees were planted and irrigated on most of the farms to provide windbreaks and shade. When the farms were abandoned in 1943, some of the trees died but others have persisted, presumably because their roots are deep enough to contact groundwater. Today these trees serve as nesting platforms for several species of birds, including hawks, owls,

ravens, magpies, and great blue herons, and as night roosts for wintering bald eagles (Rickard and Watson 1985). The following vegetation types and land use areas occur across the Hanford Site (shown in Figure 4.3-1):

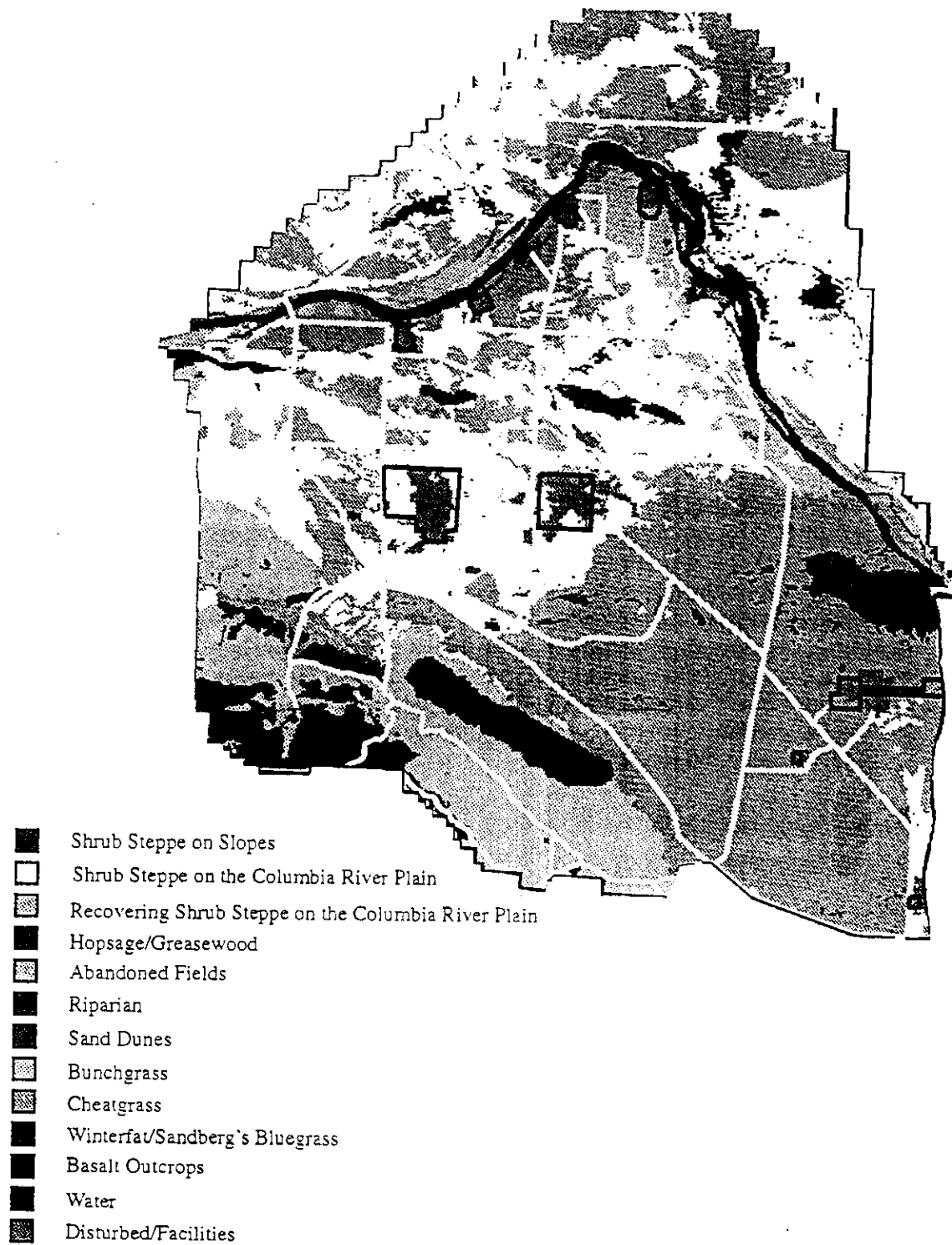
- shrub steppe on slopes
- shrub steppe on the Columbia River Plain
- recovering shrub steppe on the Columbia River Plain
- hopsage/greasewood
- abandoned fields
- riparian
- sand dunes
- bunchgrass
- cheatgrass
- winterfat/Sandberg's bluegrass
- basalt outcrops.

Several different plant communities may be mapped as one vegetation type. Shrub-steppe on slopes includes plant communities dominated by either big sagebrush or three-tip sagebrush with an understory of bluebunch wheatgrass. Shrub-steppe on the Columbia River Plain includes communities dominated by big sagebrush and/or bitterbrush with cheatgrass or Sandberg's bluegrass in the understory. Recovering shrub-steppe on the Columbia River Plain describes those communities where the shrub component was removed by wildfires over the past decade, but shrubs are reestablishing. Basalt outcrops are most often occupied by plant communities dominated by buckwheat and Sandberg's bluegrass. Abandoned fields are usually colonized by alien annual plants such as cheatgrass, tumble mustard, bulbous bluegrass, or tansy mustard. A list of plants common to the Hanford Site is given in Table 4.3-1.

The release of water used as industrial-process coolant streams at the Hanford Site facilities created several semipermanent artificial ponds that did not exist before these industrial releases commenced. Over the years, stands of cattails, reeds, and trees, especially willow, cottonwood, and Russian olive, have developed around the ponds. These ponds are ephemeral and will disappear if the industrial release of water is terminated; in fact, many of these have been discontinued and no longer exist.

Almost 600 species of plants have been identified on the Hanford Site (Sackschewsky et al. 1992). The dominant plants on the 200-Area Plateau are big sagebrush, rabbitbrush, cheatgrass, and Sandberg's bluegrass, with cheatgrass providing half of the total plant cover. Cottonwood, willows, cattails, and bulrushes grow along the banks of ponds and ditches. Near the 100 Areas, cheatgrass and riparian plants are the most prevalent, and big sagebrush, bitterbrush, rabbitbrush, cheatgrass, and Sandberg's bluegrass are common in the 300 and 400 Areas. More than 100 species of plants have been identified in the 200-Area Plateau (ERDA 1975). Cheatgrass and Russian thistle, which are annuals introduced to the United States from Eurasia in the late 1800s, invade areas where the ground surface has been disturbed. A food web centered on cheatgrass is shown in Figure 4.3-2 (modified from Watson et al. 1984). The main links leading to man would be through mule deer and chukar partridge. Other significant pathways leading to man through terrestrial

Vegetation/Land Use Map for the Hanford Site, 1994
Revised July, 29, 1994



Mapped from 1991 and 1987 aerial photography, Pacific Northwest Laboratory, Richland, WA.

Figure 4.3-1. Distribution of vegetation types on the Hanford Site.

Table 4.3-1. Common vascular plants on the Hanford Site.

A. Shrub-Steppe Species

Shrubs	Scientific Name
Big sagebrush	<i>Artemisia tridentata</i>
Spiny hopsage	<i>Grayia (Atriplex) spinosa</i>
Grey rabbitbrush	<i>Chrysothamnus nauseosus</i>
Green rabbitbrush	<i>Chrysothamnus viscidiflorus</i>
Bitterbrush	<i>Purshia tridentata</i>
Snowy buckwheat	<i>Eriogonum niveum</i>
Perennial Grasses	
Bluebunch wheatgrass	<i>Agropyron spicatum</i>
Bottlebrush squirreltail	<i>Sitanion hystrix</i>
Sandberg's bluegrass	<i>Poa sandbergii (secunda)</i>
Needle and thread	<i>Stipa comata</i>
Indian ricegrass	<i>Oryzopsis hymenoides</i>
Crested wheatgrass	<i>Agropyron desertorum (cristatum)^(a)</i>
Thick-spike wheatgrass	<i>Agropyron dasystachyum</i>
Sand dropseed	<i>Sporobolus cryptandrus</i>
Perennial Forbs	
Turpentine cymopterus	<i>Cymopterus terebinthinus</i>
Comandra	<i>Comandra umbellata</i>
Scurf pea	<i>Psoralea lanceolata</i>
Pale evening primrose	<i>Oenothera pallida</i>
Cluster lily	<i>Brodiaea douglasii</i>
Yellow bell	<i>Fritillaria pudica</i>
Sandwort	<i>Arenaria franklinii</i>
Long-leaved phlox	<i>Phlox longifolia</i>
Thelypody	<i>Thelypodium lancinatum</i>
Balsamroot	<i>Balsamorhiza careyana</i>
Cusick's sandflower	<i>Helianthus cusickii</i>
Desert mallow	<i>Sphaeralcea munroana</i>
Beard's tongue	<i>Penstemon acuminatus</i>
Sand dock	<i>Rumex venosus</i>
Yarrow	<i>Achillea millefolium</i>
Gray's desert parsley	<i>Lomatium grayi</i>
Buckwheat milkvetch	<i>Astragalus caricinus</i>
Stalked-pod milkvetch	<i>Astragalus sclerocarpus</i>
Threadleaf milkbane	<i>Erigeron filifolius</i>
Hoary aster	<i>Machaeranthera canescens</i>
Annual Forbs	
Jim Hill (tumble) mustard	<i>Sisymbrium altissimum^(a)</i>
Tansy mustard	<i>Descurainia pinnata</i>
Spring draba	<i>Draba verna^(a)</i>
Microsteris	<i>Microsteris gracilis</i>

Table 4.3-1. (contd)

<u>Annual Forbs (contd)</u>	<u>Scientific Name</u>
Matted cryptantha	<i>Cryptantha circumscissa</i>
Hawk's beard	<i>Crepis atrabarba</i>
Western wall flower	<i>Erysimum asperum</i>
Jagged chickweed	<i>Holosteum umbellatum</i> ^(a)
Polemonium	<i>Polemonium micranthum</i>
Blazing star	<i>Mentzelia albicaulis</i>
Phacelia	<i>Phacelia linearis</i>
Yellow salsify	<i>Tragopogon dubius</i> ^(a)
Russian thistle (tumbleweed)	<i>Salsola kali</i> ^(a)
Indian wheat	<i>Plantago patagonica</i>
Tarweed fiddleneck	<i>Amsinckia lycopoides</i>
Pepperweed	<i>Lepidium perfoliatum</i>
Purple mustard	<i>Chorispura tenella</i> ^(a)
False yarrow	<i>Chaenactis douglasii</i>
Cryptantha	<i>Cryptantha pterocarya</i>
Willow-herb	<i>Epilobium paniculatum</i>
Plectritis	<i>Plectritis macrocera</i>
Ragweed	<i>Ambrosia acanthicarpa</i>
Prickly lettuce	<i>Lactuca serriola</i> ^(a)
Filaree (crane's bill)	<i>Erodium cicutarium</i> ^(a)
<u>Annual Grasses</u>	
Cheatgrass	<i>Bromus tectorum</i> ^(a)
Six-weeks fescue	<i>Festuca octoflora</i>
Small fescue	<i>Festuca microstachys</i>
B. Riparian Plants	
<u>Trees and Shrubs</u>	
Black cottonwood	<i>Populus trichocarpa</i>
Black locust	<i>Robinia pseudo-acacia</i>
Peach, apricot, cherry	<i>Prunus</i> spp.
Sand bar willow	<i>Salix exigua</i>
Peachleaf willow	<i>Salix amygdaloides</i>
Willow	<i>Salix</i> spp.
Mulberry	<i>Morus alba</i> ^(a)
Dogbane	<i>Apocynum cannabinum</i>
<u>Perennial Grasses and Forbs</u>	
Reed canary grass	<i>Phalaris arundinacea</i> ^(b)
Cattail	<i>Typha latifolia</i> ^(b)
Bulrushes	<i>Scirpus</i> spp. ^(b)
Tickseed	<i>Coreopsis atkinsonia</i>
Golden aster	<i>Heterotheca villosa</i>
Gumweed	<i>Grindelia columbiana</i>

Table 4.3-1. (contd)

<u>Perennial Grasses and Forbs (contd)</u>	<u>Scientific Name</u>
Goldenrod	<i>Solidago occidentalis</i>
Prairie sage	<i>Artemisia ludoviciana</i>
Pacific sage	<i>Artemisia campestris</i>
Horsetails	<i>Equisetum</i> spp.
Gaillardia	<i>Gaillardia aristata</i>
Lupine	<i>Lupinus</i> spp.
Smartweed	<i>Polygonum persicaria</i>
Sedge	<i>Carex</i> spp. ^(b)
Wiregrass	<i>Eleocharis</i> spp. ^(b)
Speedwell	<i>Veronica anagallis-aquatica</i>
Wild onion	<i>Allium</i> spp.
Russian knapweed	<i>Centurea repens</i> ^(a)
Rushes	<i>Juncus</i> spp.
<hr/>	
<u>Aquatic Vascular</u>	
Water milfoil	<i>Myriophyllum spicatum</i>
Waterweed	<i>Elodea canadensis</i>
Pondweed	<i>Potamogeton</i> spp.
Persistent sepal yellow cress	<i>Rorippa columbiae</i>
Watercress	<i>Rorippa nasturtium-aquaticum</i>
Duckweed	<i>Lemna minor</i>

(a) Exotic.

(b) Perennial grasses and graminoids.

food webs would be via geese, ducks, upland game birds, elk, and asparagus. Certain desert plants have roots that grow to depths approaching 10 m (33 ft) (Napier 1982); however, root penetration to these depths has not been demonstrated for plants in the 200 Areas. Rabbitbrush roots have been found at a depth of 2.4 m (8 ft) near the 200 Areas (Klepper et al. 1979). Mosses and lichens appear abundantly on the soil surface; lichens commonly grow on the shrub stems.

The important desert shrubs, big sagebrush and bitterbrush, are widely spaced and usually provide less than 20% canopy cover. The important understory plants are grasses, especially cheatgrass, Sandberg's bluegrass, Indian ricegrass, June grass, and needle-and-thread grass.

Compared with other semiarid regions in North America, primary productivity is relatively low and the number of vascular plant species is also low. This is attributed to the low annual precipitation (16 cm, ~6 in.), the low water-holding capacity of the rooting substrate (sand), and the droughty summers and occasionally very cold winters.

Sagebrush and bitterbrush are easily killed by summer wildfires, but the grasses and other herbs are relatively resistant and usually recover in the first growing season after

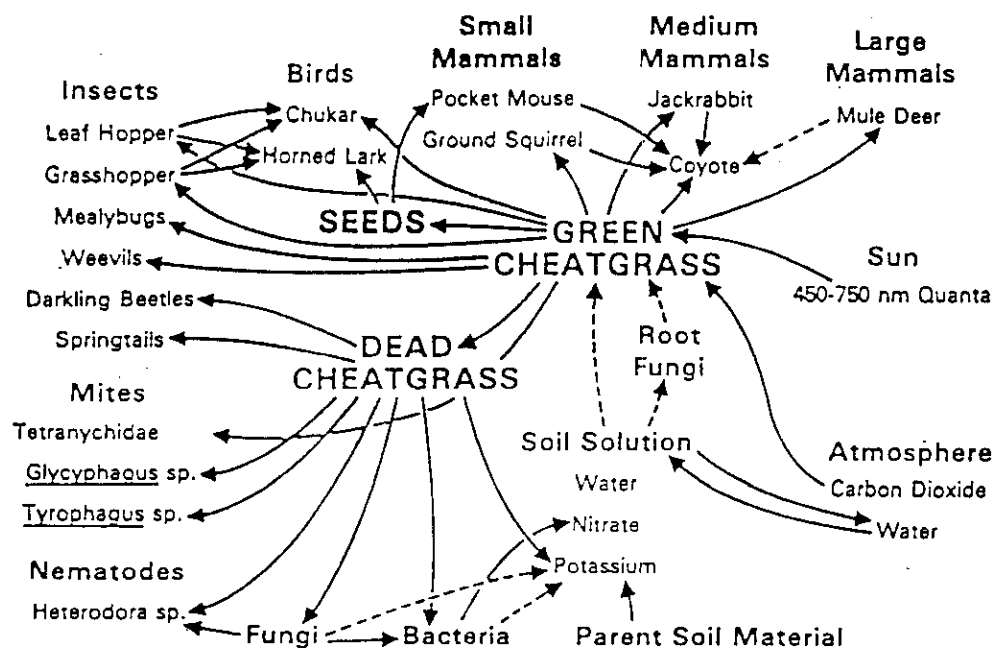


Figure 4.3-2. Food web centered on cheatgrass (modified from Watson et al. 1984). Arrows indicate direction of energy and mass transfer.

burning. Fire usually opens the community to wind erosion. The severity of erosion depends on the severity and areal extent of the fire. Hot fires incinerate entire shrubs and damage grasscrowns. Less intensive fires leave dead stems standing, and recovery of herbs is prompt. The most recent and extensive wildfire occurred in the summer of 1984.

Bitterbrush shrubs provide browse for a resident herd of wild mule deer. Bitterbrush shrubs are slow to recolonize burned areas because invasion is by seeds. Bitterbrush does not sprout even when fire damage is relatively light.

Certain passerine birds rely on sagebrush or bitterbrush for nesting (e.g., sage sparrow, sage thrasher, and loggerhead shrike). These birds are not expected to nest in places devoid of shrubs. Jackrabbits also apparently avoid burned areas without shrubs. Birds that nest on the ground in areas without shrubs are longbilled curlews, horned larks, Western meadowlarks, and burrowing owls.

Insects

More than 300 species of terrestrial and aquatic insects have been found on the Hanford Site (ERDA 1975); however, the total number of species known to exist on the

Site probably exceeds 600.^(a) Grasshoppers and darkling beetles are among the more conspicuous groups and, along with other species, are important in the food web of local birds and mammals. Most species of darkling beetles occur throughout the spring-to-fall period, although some species are present only during 2 or 3 months in the fall (Rogers and Rickard 1977). Grasshoppers are evident during the late spring to fall. Both groups are subject to wide annual variations in abundance. A food web centered on grasshoppers is shown in Figure 4.3-3 (Watson et al. 1984). The link leading to the Swainson's hawk is of concern in this case because it is a federal candidate for threatened and endangered designation.

An estimation of the relative densities of various insect taxa is given in Table 4.3-2.

Reptiles and Amphibians

Twelve species (Table 4.3-3) of amphibians and reptiles are known to occur on the Hanford Site (Fitzner and Gray 1991). The occurrence of these species is infrequent compared with similar fauna of the southwestern United States. The side-blotched lizard is the most abundant reptile and can be found throughout the Hanford Site. Short-horned and sagebrush lizards are also common in selected habitats. The most common snakes are the gopher snake, the yellow-bellied racer, and the Pacific rattlesnake, which are found throughout the Hanford Site. Striped whipsnakes and desert night snakes are rarely found, but some sightings have been recorded for the site. Toads and frogs are found near the permanent water bodies and along the Columbia River.

Birds

Fitzner and Gray (1991) and Landeen et al. (1992) have presented data on birds observed on the Hanford Site. The horned lark and western meadowlark are the most abundant nesting birds in the shrub-steppe. Some of the more common birds present on the Hanford Site are listed in Table 4.3-4.

Birds Inhabiting Riverine Habitats. The most abundant game birds nesting in riverine habitats are the Canada goose (Hanson and Eberhardt 1971), ring-necked pheasant, and California quail. Mallards also nest there but in smaller numbers. The Columbia River serves as an important resting stop for many species of migrating waterfowl and shore-birds. In fall and winter months, thousands of ducks (mostly mallards) and geese (mostly Canada geese) rest on the Columbia River islands and shoreline. Large numbers of waterfowl occur on the river between the abandoned Hanford Townsite and the Vernita Bridge, a river section that is closed to waterfowl shooting during the hunting season. The Hanford Site is located in the Pacific Flyway; in addition, a major sandhill crane flyway passes over the site.

(a) Lee Rogers, Pacific Northwest Laboratory, personal communication.

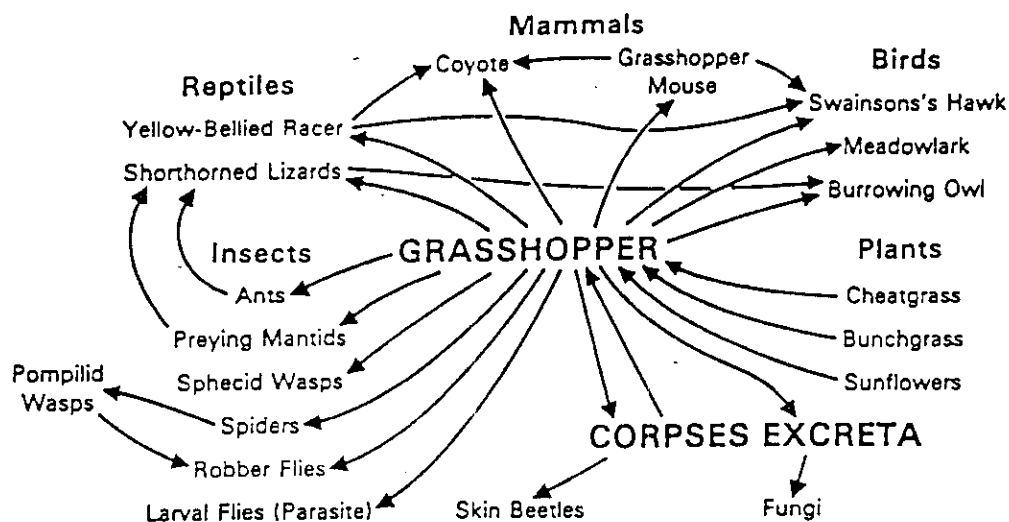


Figure 4.3-3. Food web centered on grasshoppers (from Watson et al. 1984).
Arrows indicate direction of energy and mass transfer.

Table 4.3-2. Relative abundance (%) of insect taxa collected from sagebrush, rabbitbrush, and hopsage (Rogers 1979).

<u>Taxa</u>	<u>Sagebrush</u>	<u>Rabbitbrush</u>	<u>Hopsage</u>
Hemiptera	44.6	11.7	6.4
Homoptera	33.0	31.2	6.1
Orthoptera	7.3	24.0	21.8
Araneida	6.5	20.7	21.3
Hymenoptera	4.2	2.9	5.8
Coleoptera	1.7	1.9	27.4
Lepidoptera	1.2	6.1	5.3
Diptera	1.1	1.2	5.3
Neuroptera	0.3	0.3	0.3
Other	0.1	0.1	0.3

Table 4.3-3. Amphibians and reptiles occurring on the Hanford Site.

<u>Common Name</u>	<u>Scientific Name</u>
<u>Amphibians</u>	
Great Basin spadefoot toad	<i>Scaphiopus intermontanus</i>
Woodhouse's toad	<i>Bufo woodhousii</i>
Pacific treefrog	<i>Hyla regilla</i>
<u>Reptiles</u>	
Sagebrush lizard	<i>Sceloporus graciosus</i>
Side-blotched lizard	<i>Uta stansburiana</i>
Short-horned lizard	<i>Phrynosoma douglassii</i>
Striped whipsnake	<i>Masticophis taeniatus</i>
Western yellow-bellied racer	<i>Coluber constrictor</i>
Gopher snake	<i>Pituophis melanoleucus</i>
Desert night snake	<i>Hypsiglena torquata</i>
Western rattlesnake	<i>Crotalus viridis</i>
Painted turtle	<i>Chrysemys picta</i>

Islands in the river also provide nesting sites for thousands of ring-billed gulls and California gulls and a few hundred Forster's terns. Shoreline trees and powerline towers serve as nesting sites for colonies of great blue herons.

Bald eagles regularly visit the riverine habitat in winter. Bald eagles are attracted to the Hanford Site's Columbia River habitat because of an abundance of food in the form of salmon carcasses and waterfowl, the presence of trees that serve as daytime perches and nighttime roosts, and freedom from many kinds of human activities. Large numbers of cliff and bank swallows nest on the steep bluffs overlooking the Columbia River.

White pelicans, double-crested cormorants, common loons, and ospreys are present along the Columbia River during spring months, but only loons have been observed to nest there.

Many species of songbirds nest in the narrow corridor of streamside thickets along the Columbia River. Results of monitoring surveys for these species can be found in Sackschewsky and Landeen (1992).

Wastewater ponds at the Hanford Site were important habitats for songbirds, shore birds, ducks, and geese (Fitzner and Price 1973; Fitzner and Rickard 1975; Fitzner and

Table 4.3-4. Partial list of common birds found on the Hanford Site.

<u>Common Name</u>	<u>Scientific Name</u>
Great blue heron	<i>Ardea herodias</i>
Canada goose	<i>Branta canadensis moffitti</i>
Mallard	<i>Anas platyrhynchos</i>
Red-tailed hawk	<i>Buteo jamaicensis</i>
Swainson's hawk	<i>Buteo swainsoni</i>
Rough-legged hawk	<i>Buteo lagopus</i>
California quail	<i>Callipepla californicus</i>
Ring-necked pheasant	<i>Phasianus colchicus</i>
Chukar partridge	<i>Alectoris chukar</i>
Gray (Hungarian) partridge	<i>Perdix perdix</i>
American coot	<i>Fulica americana</i>
California gull	<i>Larus californicus</i>
Ring-billed gull	<i>Larus delawarensis</i>
Western kingbird	<i>Tyrannus verticalis</i>
Common raven	<i>Corvus corax</i>
Mourning dove	<i>Zenaidura macroura</i>
Horned lark	<i>Eremophila alpestris</i>
Black-billed magpie	<i>Pica pica</i>
Western meadowlark	<i>Sturnella neglecta</i>
Sage sparrow	<i>Amphispiza belli</i>
Barn swallow	<i>Hirundo rustica</i>
Cliff swallow	<i>Hirundo pyrrhonota</i>
Pied-billed grebe	<i>Podilymbus podiceps</i>
Northern shoveler	<i>Anas clypeata</i>
Bufflehead	<i>Bucephala albeola</i>
Northern harrier	<i>Circus cyaneus</i>
American kestrel	<i>Falco sparverius</i>
Killdeer	<i>Charadrius vociferus</i>
Rock dove	<i>Columbia livia</i>
Common nighthawk	<i>Chordeiles minor</i>
American robin	<i>Turdus migratorius</i>
European starling	<i>Sturnus vulgaris</i>
Red-winged blackbird	<i>Agelaius phoeniceus</i>
White-crowned sparrow	<i>Zonotrichia leucophrys</i>
House finch	<i>Carpodacus mexicanus</i>
House sparrow	<i>Passer domesticus</i>

Schreckhise 1979), but most of these have been eliminated. The American coot is an abundant aquatic nesting bird on these sites. The ponds are used by a variety of waterfowl during fall migration. The most important resident waterfowl is the Canada goose, whose nesting habitat is confined to the islands of the free-flowing reach of the Columbia River (Hanson and Eberhardt 1971).

Birds Inhabiting Terrestrial Habitats. The game birds inhabiting terrestrial habitats at Hanford are the chukar, gray partridge, and mourning dove. The chukar and partridge are year-round residents, but mourning doves are migrants, although a few doves overwinter in

southeastern Washington State; most leave the area by the end of September. Mourning doves nest on the ground and in trees all across the Hanford Site. Chukars are most numerous in the Rattlesnake Hills, Yakima Ridge, Umtanum Ridge, Saddle Mountains, and Gable Mountain areas of the Hanford Site. A few birds also inhabit the 200-Area Plateau. A food web centered on chukar partridge is shown in Figure 4.3-4 (Watson et al. 1984). Gray partridges are not as numerous as chukars, and their numbers also vary greatly from year to year. Sage grouse populations have declined on the Hanford Site since the 1940s, and it is likely that there are no nesting grouse on the Site at this time. The nearest viable population is located on the U.S. Army's Yakima Training Center, located to the north and west of the Hanford Site. In recent years, the number of nesting ferruginous hawks has increased, at least in part because the hawks have accepted steel powerline towers as nesting sites. Only about 50 pairs are believed to be nesting in the state of Washington. Other raptors that nest on the Hanford Site are the prairie falcon, northern harrier, red-tailed hawk, Swainson's hawk, and kestrel. Burrowing owls, great horned owls, barn owls, and long-eared owls also nest on the Site, but in smaller numbers.

Mammals

Approximately 39 species of mammals have been identified on the Hanford Site (Fitzner and Gray 1991) (Table 4.3-5).

Mammals Inhabiting Riverine Habitats. The Columbia River and adjacent shoreline support populations of beaver, muskrat, mink, raccoon, and striped skunk. Coyotes are common, but bobcats are seldom seen. Mule deer forage on shoreline plants and seek shade provided by shoreline trees, especially during the hot, dry summer months.

Mammals Inhabiting Terrestrial Habitats. The largest vertebrate predator inhabiting the Hanford Site is the coyote, which ranges all across the Site. Coyotes have been a major cause of destruction of Canada goose nests on Columbia River Islands, especially islands upstream of the abandoned Hanford townsite. Bobcats and badgers also inhabit the Hanford Site but in low numbers.

Black-tailed jackrabbits are common on the Hanford Site, mostly associated with mature stands of sagebrush. Cottontails are also common but appear to be more closely associated with the buildings, debris piles, and equipment laydown areas associated with the onsite laboratory and industrial facilities.

Townsend's ground squirrels occur in colonies of various sizes scattered across the Hanford Site but marmots are scarce. The most abundant mammal inhabiting the Site is the Great Basin pocket mouse. It occurs all across the Columbia River plain and on the slopes of the surrounding ridges. Other small mammals include the deer mouse, harvest mouse, grasshopper mouse, montane vole, vagrant shrew, and Merriam's shrew.

Seven species of bats inhabit the Hanford Site, occurring mostly as fall or winter migrants. The pallid bat frequents deserted buildings and is thought to be the most abundant of the various species. Other species include the hoary bat, silver-haired bat, California brown bat, little brown bat, Yuma brown bat, and Pacific western big-eared bat.

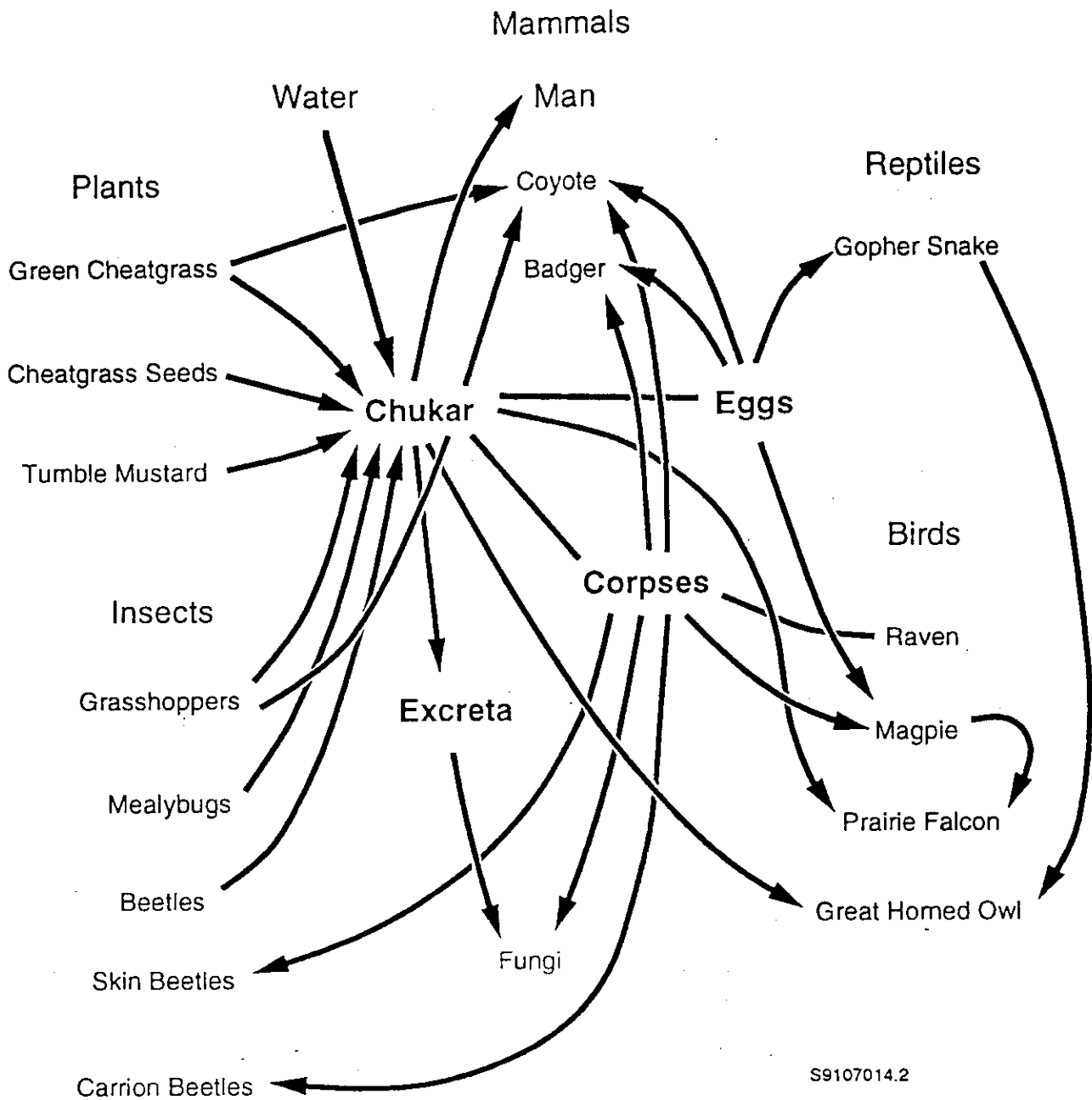


Figure 4.3-4. Food web centered on chukar partridge (from Watson et al. 1984). Arrows indicate direction of energy and mass transfer.

Table 4.3-5. List of mammals occurring on the Hanford Site.

Common Name	Scientific Name
Merriam's shrew	<i>Sorex merriami</i>
Vagrant shrew	<i>Sorex vagrans</i>
Pacific western big-eared bat	<i>Plecotus townsendii townsendii</i>
Little brown bat	<i>Myotis lucifugus</i>
Silver-haired bat	<i>Lasionycteris noctivagans</i>
California brown bat	<i>Myotis californicus</i>
Yuma brown bat	<i>Myotis yumanensis</i>
Pallid bat	<i>Antrozous pallidus</i>
Hoary bat	<i>Lasiurus cinereus</i>
Raccoon	<i>Procyon lotor</i>
Mink	<i>Mustela vison</i>
Long-tailed weasel	<i>Mustela frenata</i>
Short-tailed weasel	<i>Mustela ermineu</i>
Badger	<i>Taxidea taxis</i>
Striped skunk	<i>Mephitis mephitis</i>
Coyote	<i>Canis latrans</i>
Bobcat	<i>Lynx rufus</i>
Least chipmunk	<i>Eutamias minimus</i>
Yellow-bellied marmot	<i>Marmota flaviventris</i>
Townsend's ground squirrel	<i>Spermophilus townsendii</i>
Northern pocket gopher	<i>Thomomys talpoides</i>
Great Basin pocket mouse	<i>Perognathus parvus</i>
Beaver	<i>Castor canadensis</i>
Western harvest mouse	<i>Reithrodontomys megalotis</i>
Deer mouse	<i>Peromyscus maniculatus</i>
Northern grasshopper mouse	<i>Onychomys leucogaster</i>
Montane meadow mouse	<i>Microtus montanus</i>
Bushy-tailed woodrat	<i>Neotoma cinerea</i>
Sagebrush vole	<i>Lagurus curtatus</i>
Muskrat	<i>Ondatra zibethicus</i>
House mouse	<i>Mus musculus</i>
Norway rat	<i>Rattus norvegicus</i>
Porcupine	<i>Erethizon dorsatum</i>
Black-tailed jackrabbit	<i>Lepus californicus</i>
White-tailed jackrabbit	<i>Lepus townsendi</i>
Nuttall's cottontail rabbit	<i>Sylvilagus nuttallii</i>
Pygmy rabbit	<i>Brachylagus idahoensis</i>
Mule deer	<i>Odocoileus hemionus</i>
White-tailed deer	<i>Odocoileus virginianus</i>
Elk	<i>Cervus elaphus</i>
Otter	<i>Lutra canadensis</i>

A herd of Rocky Mountain elk is present on the Fitzner-Eberhardt Arid Lands Ecology (ALE) Reserve (Figure 4.3-5). It is believed that these animals immigrated to the ALE Reserve from the Cascade Mountains in the early 1970s. This herd had grown from approximately 6 animals in 1972 to 119 individuals in spring of 1992. Elk frequently move off the ALE Reserve to private lands located to the north and west, particularly during late spring, summer, and early fall. However, while the elk are on the Hanford Site, they restrict their activities to the ALE Reserve. Lack of water and the high level of human activity presumably restrict the elk from using other areas of the Hanford Site. Despite the arid climate and their unusual habitat, these elk appear to be very healthy; antler and body size for given age-classes are among the highest recorded for this species (McCorquodale et al. 1989). In addition, reproductive output is also among the highest recorded for this species (McCorquodale et al. 1988). Elk remain on the ALE Reserve because of the protection it provides from human disturbance.

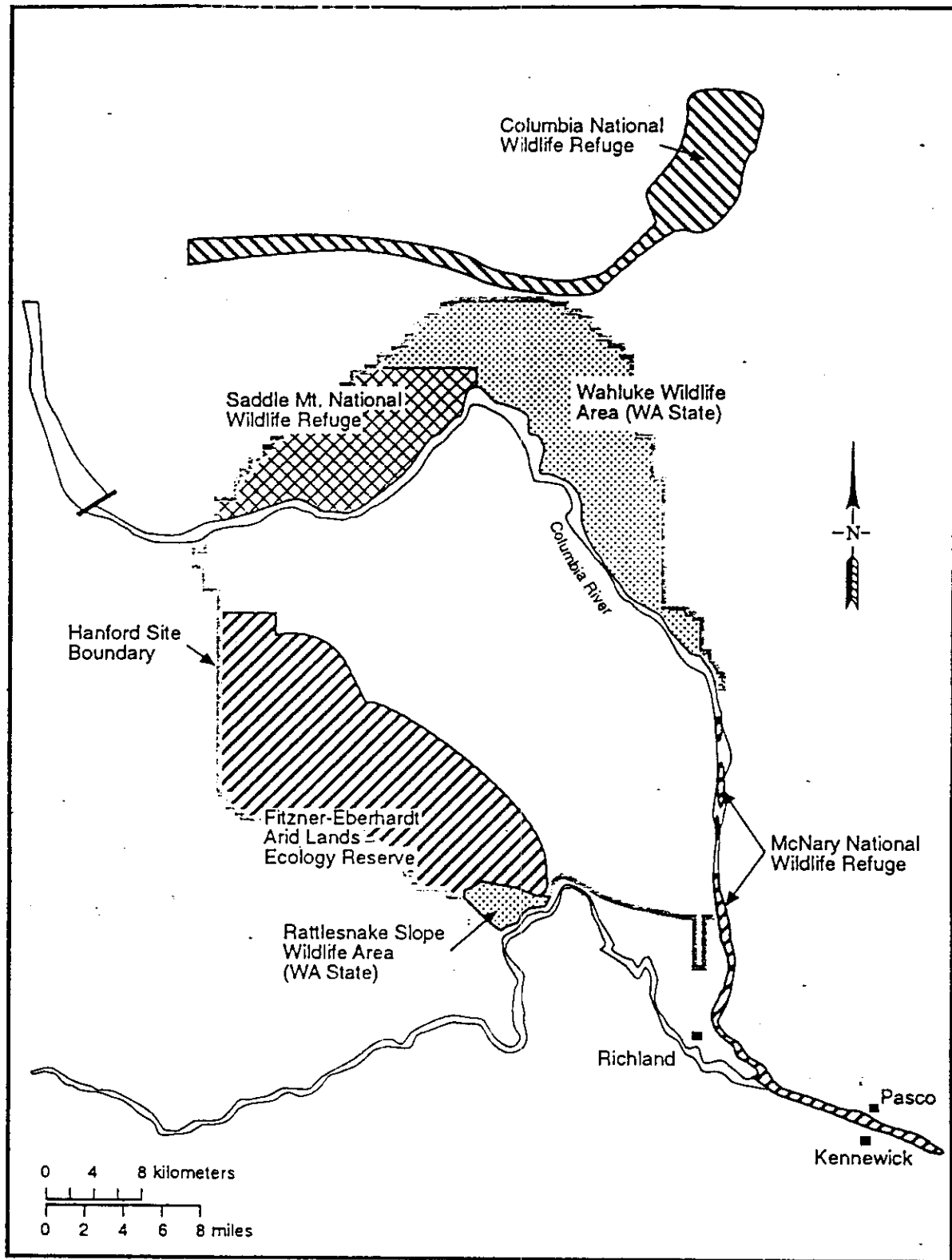
Mule deer are found throughout the Hanford Site, although areas of highest concentrations are on the ALE Reserve and along the Columbia River. Deer populations on the Hanford Site appear to be relatively stable. The herd is characterized by a large proportion of very old animals (Eberhardt et al. 1982) and high fawn mortality from coyote predation (Steigers and Flinders 1980). Islands in the Hanford Reach of the Columbia River are used extensively as fawning sites by the deer (Eberhardt et al. 1979) and thus are a very important habitat for this species. Hanford Site deer frequently move offsite and are killed by hunters on adjacent public and private lands (Eberhardt et al. 1984).

4.3.2 Aquatic Ecology

There are two types of natural aquatic habitats on the Hanford Site: one is the Columbia River, which flows along the northern and eastern edges of the Hanford Site, and the other is provided by the small spring-streams and seeps located mainly on the ALE site in the Rattlesnake Hills. Several artificial water bodies, both ponds and ditches, have been formed as a result of wastewater disposal practices associated with operation of the reactors and separation facilities. These are temporary and will vanish with cessation of activities; while present, however, they form established aquatic ecosystems (except West Pond) complete with representative flora and fauna (Emery and McShane 1980). West Pond is created by a rise in the water table in the 200 Areas and is not fed by surface flow; thus, it is alkaline and has a greatly restricted complement of biota.

The Columbia River

The Columbia River is the dominant aquatic ecosystem on the Hanford Site and supports a large and diverse community of plankton, benthic invertebrates, fish, and other communities. It is the fifth largest river in North America with a total length of about 2000 km (~1240 mi) from its origin in British Columbia to its mouth at the Pacific Ocean. The Columbia has been dammed both upstream and downstream from the Hanford Site, and the reach flowing through the area is the last free-flowing, but regulated, reach of the Columbia River in the United States above Bonneville Dam. Plankton populations in the Hanford Reach are influenced by communities that develop in the reservoirs of upstream dams, particularly Priest Rapids Reservoir, and by manipulation of water levels below by



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Figure 4.3-5. National and State wildlife refuges in the vicinity of the Hanford Site.

dam operations in downstream reservoirs. Phytoplankton and zooplankton populations at Hanford are largely transient, flowing from one reservoir to another. There is generally insufficient time for characteristic endemic groups of phytoplankton and zooplankton to develop in the Hanford Reach. No tributaries enter the Columbia during its passage through the Hanford Site.

The Columbia River is a very complex ecosystem because of its size, the number of humanmade alterations, the biotic diversity, and size and diversity of its drainage basin. Streams in general, especially smaller ones, usually depend on organic matter from outside sources (terrestrial plant debris) to provide energy for the ecosystem. Large rivers, particularly the Columbia River with its series of large reservoirs, contain significant populations of primary energy producers (algae, plants) that contribute to the basic energy requirements of the biota. Phytoplankton (free-floating algae) and periphyton (sessile algae) are abundant in the Columbia River and provide food for herbivores such as immature insects, which in turn are consumed by carnivorous species. Figure 4.3-6 is a simplified diagram of the food web relationships in selected Columbia River biota and represents probable major energy pathways.

Phytoplankton. Phytoplankton species identified from the Hanford Reach include diatoms, golden or yellow-brown algae, green algae, blue-green algae, red algae, and dino-flagellates. Diatoms are the dominant algae in the Columbia River phytoplankton, usually representing more than 90% of the populations. The main genera include *Asterionella*, *Cyclotella*, *Fragilaria*, *Melosira*, *Stephanodiscus*, and *Synedra* (Neitzel et al. 1982a). These are typical of those forms found in lakes and ponds and originate in the upstream reservoirs. A number of algae found as free-floating species in the Hanford Reach of the Columbia are actually derived from the periphyton; they are detached and suspended by current and frequent fluctuations of the water level.

The peak concentration of phytoplankton is observed in April and May, with a secondary peak in late summer/early autumn (Cushing 1967a). The spring pulse in phytoplankton density is probably related to increasing light and water temperature rather than to availability of nutrients, because phosphate and nitrate nutrient concentrations are never limiting. Minimum numbers are present in December and January. Green algae (Chlorophyta) and blue-green algae (Cyanophyta) occur in the phytoplankton community during warmer months, but in substantially fewer numbers than diatoms. Diversity indices, carbon uptake, and chlorophyll-a concentrations for the phytoplankton at various times and places can be found in Wolf et al. (1976), Beak Consultants Inc. (1980), and Neitzel et al. (1982a).

Periphyton. Communities of periphytic species ("benthic microflora") develop on suitable solid substrata wherever there is sufficient light for photosynthesis. Peaks of production occur in spring and late summer (Cushing 1967b). Dominant genera are the diatoms *Achnanthes*, *Asterionella*, *Cocconeis*, *Fragilaria*, *Gomphonema*, *Melosira*, *Nitzschia*, *Stephanodiscus*, and *Synedra* (Page and Neitzel 1978; Page et al. 1979; Beak Consultants Inc. 1980; Neitzel et al. 1982a).

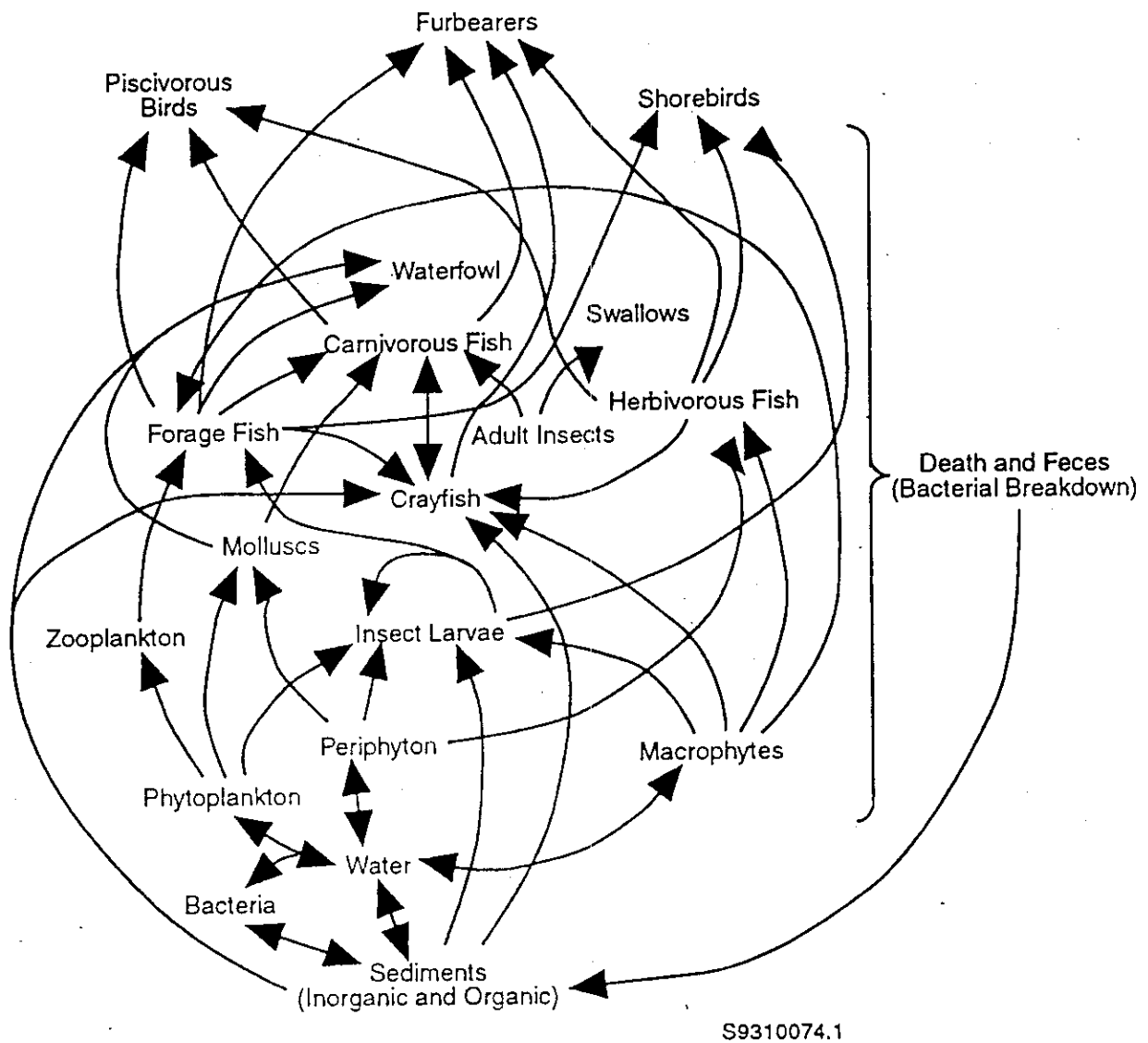


Figure 4.3-6. Interrelationships of food web components in the Columbia River ecosystem (from Cushing 1992).

Macrophytes. Macrophytes are sparse in the Columbia River because of strong currents, rocky bottom, and frequently fluctuating water levels. Rushes (*Juncus* spp.) and sedges (*Carex* spp.) occur along shorelines of the slack-water areas such as White Bluffs Slough below 100-H Area, the slough area downstream of the 100-F Area, and Hanford Slough. Macrophytes are also present along gently sloping shorelines that are subject to flooding during the spring freshet and daily fluctuating river levels (below Coyote Rapids and 100-D Area). Commonly found plants include *Lemna*, *Potamogeton*, *Elodea*, and *Myriophyllum*. Where they exist, macrophytes have considerable ecological value. They provide food and shelter for juvenile fish and spawning areas for some species of warm-water game fish. However, should some of the exotic macrophytes increase to

nuisance levels, they may encourage increased sedimentation of fine particulate matter. This could negatively affect the spawning of salmonids but enhance the possibility for increasing the range for shad by providing more suitable spawning habitat. These changes could have a significant impact on trophic relationships of the Columbia River.

Zooplankton. The zooplankton populations in the Hanford Reach of the Columbia River are generally sparse. In the open-water regions, crustacean zooplankters are dominant; dominant genera are *Bosmina*, *Diaptomus*, and *Cyclops*. Densities are lowest in winter and highest in the summer, with summer peaks dominated by *Bosmina* and ranging up to 4500 organisms/m³. Winter densities are generally <50 organisms/m³. *Diaptomus* and *Cyclops* dominate in winter and spring, respectively (Neitzel et al. 1982b).

Benthic Organisms. Benthic organisms are found either attached to or closely associated with the substratum. All major freshwater benthic taxa are represented in the Columbia River. Insect larvae such as caddisflies (Trichoptera), midge flies (Chironomidae), and black flies (Simuliidae) are dominant. Dominant caddisfly species are *Hydropsyche cockerelli*, *Cheumatopsyche campyla*, and *C. enonis*. Other benthic organisms include limpets, snails, sponges, and crayfish. Peak larval insect densities are found in late fall and winter, and the major emergence is in spring and summer (Wolf 1976). Stomach contents of fish collected in the Hanford Reach from June 1973 through March 1980 revealed that benthic invertebrates are important food items for nearly all juvenile and adult fish. There is a close relationship between food organisms in the stomach contents and those in the benthic and invertebrate drift communities.

Fish. Gray and Dauble (1977) list 43 species of fish in the Hanford Reach of the Columbia River. The brown bullhead (*Ictalurus nebulosus*) has been collected since 1977, bringing the total number of fish species identified in the Hanford Reach to 44 (Table 4.3-6). Of these species, chinook salmon, sockeye salmon, coho salmon, and steelhead trout use the river as a migration route to and from upstream spawning areas and are of the greatest economic importance. Both fall chinook salmon and steelhead trout also spawn in the Hanford Reach. The relative contribution of upper-river bright stocks to fall chinook salmon runs in the Columbia River increased from about 24% of the total in the early 1980s, to 50-60% of the total by 1988 (Dauble and Watson 1990). The destruction of other mainstream Columbia spawning grounds by dams has increased the relative importance of the Hanford Reach spawning (Watson 1970, 1973).

Upper estimates of the annual average Hanford Reach steelhead spawning population estimates based on dam counts for the years 1962-1971 were about 10,000 fish. The estimated annual sport catch for the period 1963-1968 in the reach of the river from Ringold to the mouth of the Snake River was approximately 2700 fish (Watson 1973).

Shad, another anadromous species, may also spawn in the Hanford Reach. The upstream range of the shad has been increasing since 1956 when <10 adult shad ascended McNary Dam. Since then, the number ascending Priest Rapids Dam, immediately upstream of Hanford, has risen to many thousands each year, and young-of-the-year have been collected in the Hanford Reach. The shad is not dependent on specific current and

Table 4.3-6. Fish species in the Hanford Reach of the Columbia River.

<u>Common Name</u>	<u>Scientific Name</u>
White sturgeon	<i>Acipenser transmontanus</i>
Bridgelip sucker	<i>Catostomus columbianus</i>
Largescale sucker	<i>Catostomus macrocheilus</i>
Mountain sucker	<i>Catostomus platyrhynchus</i>
Pumpkinseed	<i>Lepomis gibbosus</i>
Bluegill	<i>Lepomis macrochirus</i>
Smallmouth bass	<i>Micropterus dolomieu</i>
Largemouth bass	<i>Micropterus salmoides</i>
White crappie	<i>Pomoxis annularis</i>
Black crappie	<i>Pomoxis nigromaculatus</i>
American shad	<i>Alosa sapidissima</i>
Prickley sculpin	<i>Cottus asper</i>
Mottled sculpin	<i>Cottus bairdi</i>
Piute sculpin	<i>Cottus beldingi</i>
Reticulate sculpin	<i>Cottus perplexus</i>
Torrent sculpin	<i>Cottus rotheus</i>
Chiselmouth	<i>Acrocheilus alutaceus</i>
Carp	<i>Cyprinus carpio</i>
Peamouth	<i>Mylocheilus caurinus</i>
Northern squawfish	<i>Ptychocheilus oregonensis</i>
Longnose dace	<i>Rhinichthys cataractae</i>
Leopard dace	<i>Rhinichthys falcatus</i>
Speckled dace	<i>Rhinichthys osculus</i>
Redside shiner	<i>Richardsonius balteatus</i>
Tench	<i>Tinca tinca</i>
Burbot	<i>Lota lota</i>
Threespine stickleback	<i>Gasterosteus aculeatus</i>
Black bullhead	<i>Ictalurus melas</i>
Yellow bullhead	<i>Ictalurus natalis</i>
Brown bullhead	<i>Ictalurus nebulosus</i>
Channel catfish	<i>Ictalurus punctatus</i>
Yellow perch	<i>Perca flavescens</i>
Walleye	<i>Stizostedion vitreum vitreum</i>
Sand roller	<i>Percopsis transmontana</i>
Pacific lamprey	<i>Entosphenus tridentatus</i>
River lamprey	<i>Lampetra ayresi</i>
Lake whitefish	<i>Coregonus clupeaformis</i>
Coho salmon	<i>Oncorhynchus kisutch</i>
Sockeye salmon	<i>Oncorhynchus nerka</i>
Chinook salmon	<i>Oncorhynchus tshawytscha</i>
Mountain whitefish	<i>Prosopium williamsoni</i>
Cutthroat trout	<i>Oncorhynchus clarki</i>
Rainbow trout (steelhead)	<i>Oncorhynchus mykiss</i>
Dolly Varden	<i>Salvelinus malma</i>

bottom conditions required by the salmonids for spawning and has apparently found favorable conditions for reproduction throughout much of the Columbia and Snake rivers.

Other fish of importance to sport fishermen are whitefish, sturgeon, smallmouth bass, crappie, catfish, walleye, and perch. Large populations of rough fish are also present, including carp, shiners, suckers, and squawfish.

Spring Streams

Small spring streams, such as Rattlesnake and Snively springs, contain diverse biotic communities and are extremely productive (Cushing and Wolf 1984). Dense blooms of watercress occur that are not lost until one of the major flash floods occurs. Aquatic insect production is fairly high as compared with mountain streams (Gaines 1987). The macrobenthic biota varies from site to site and is related to the proximity of colonizing insects and other factors.

Rattlesnake Springs, on the western side of the Hanford Reservation, forms a small surface stream that flows for about 2.5 km (1.6 mi) before disappearing into the ground as a result of seepage and evapotranspiration. Base flow of this stream is about 0.01 m³/sec (0.4 cfs) (Cushing and Wolf 1982). Water temperature ranges from 2° to 22°C (36 to 72°F). Mean annual total alkalinities (as CaCO₃, nitrate nitrogen, phosphate phosphorus, and total dissolved solids) are 127, 0.3, 0.18, and 217 mg/L, respectively (Cushing and Wolf 1982; Cushing et al. 1980). The sodium content of the spring water is about 7 ppm (Brown 1970). Rattlesnake Springs is of ecological importance because it provides a source of water to terrestrial animals in an otherwise arid part of the reservation. Snively Springs, located farther west and at a higher elevation than Rattlesnake Springs, apparently does not contribute to the flow of Rattlesnake Springs (Brown 1970), but probably flows to the west and off the Hanford Site. The major rooted aquatic plant, which in places may cover the entire width of the stream, is watercress (*Nasturtium officinale* = *Rorippa nasturtium-aquaticum*). Isolated patches of bulrush (*Scirpus* sp.), spike rush (*Eleocharis* sp.), and cattail (*Typha latifolia*) occupy <5% of the stream bed.

Primary productivity at Rattlesnake Springs is greatest during the spring and coincident with the maximum periphyton standing crop. Net primary productivity averaged 0.9 g cm²/day during 1969-1970; the spring maximum was 2.2 g cm⁻².day⁻¹. Seasonal productivity and respiration rates are within the ranges reported for arid region streams. Although Rattlesnake Springs is a net exporter of organic matter during much of the growing season, it is subject to flash floods and severe scouring and denuding of the streambed during winter and early spring, making it an importer of organic materials on an annual basis (Cushing and Wolf 1984).

Secondary production is dominated by detritus-feeding collector-gatherer insects (mostly Chironomidae and Simuliidae) that have multiple cohorts and short generation times (Gaines et al. 1992). Overall production is not high and is likely related to the low diversity found in these systems related to the winter spates that scour the spring-streams. Total secondary production in Rattlesnake Springs and Snively Springs is 16,356 and 14,154 g DWm⁻².yr⁻¹, respectively. There is an indication that insects in these spring-

streams depend on both autochthonous and allochthonous primary production as an energy source, despite significant shading of these spring-streams that would appear to preclude significant autochthonous production (Mize 1993).

An inventory of the many springs occurring on the Rattlesnake Hills has been published by Schwab et al. (1979). Limited physical and chemical data are included for each site.

Wetlands

Several habitats on the Hanford Site could be considered wetlands. The largest wetland habitat is the riparian zone bordering the Columbia River. The extent of this zone varies but includes extensive stands of willows, grasses, various aquatic macrophytes, and other plants. The zone is extensively impacted by both seasonal water-level fluctuations and daily variations related to power generation at Priest Rapids Dam immediately upstream of the Site.

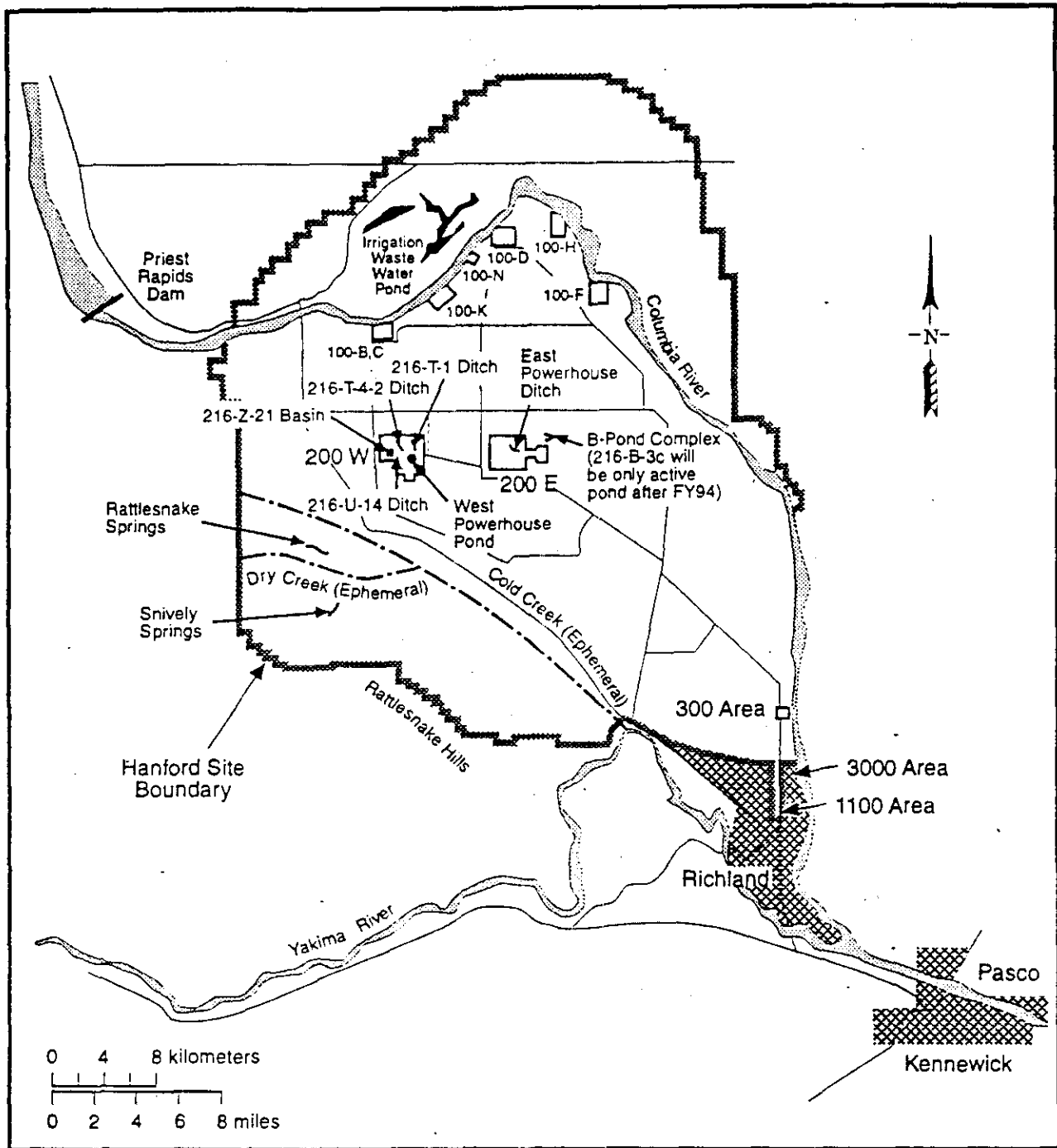
Other extensive areas of wetlands can be found within the Saddle Mt. National Wildlife Refuge and the Wahluke Wildlife Area; these two areas encompass all the lands extending from the north bank of the Columbia River northward to the Site boundary and east of the Columbia River down to Ringold Springs. Wetland habitat in these areas consists of fairly large pond habitat resulting from irrigation runoff (Figure 4.3-7). These ponds have extensive stands of cattails (*Typha* sp.) and other emergent aquatic vegetation surrounding the open-water regions. They are extensively used as resting sites by waterfowl.

Some wetlands habitat exists in the riparian zones of some of the larger spring streams on the Fitzner-Eberhardt ALE Reserve of the Hanford Site (see earlier description). These are not extensive and usually amount to less than a hectare in size, although the riparian zone along Rattlesnake Springs is probably about 2 km in length and consists of peachleaf willows, cattails, and other plants.

The U.S. Fish and Wildlife Service has published a series of 1:24,000 maps that show the locations of wetlands. An accompanying booklet describes how to use these maps. Four sets of these maps, covering the Hanford Site, and the instructional booklet for their use, are available. They are located at 1) the office of editor C. E. Cushing, Sigma 4 Building/Room 307 (PNL); 2) the Technical Library, PNL; 3) the office of the Richland Office NEPA Compliance Officer; and 4) the Westinghouse Hanford Company, Environmental Division.

Temporary Water Bodies

The temporary wastewater ponds and ditches have been in place for as long as two decades, although many have been eliminated. Rickard et al. (1981) discussed the ecology of Gable Mountain Pond, one of the former major lentic sites. Emery and McShane (1980) presented ecological characteristics of all the temporary sites. The ponds develop luxuriant riparian communities and become quite attractive to autumn and spring migrating birds; several species nest in the vicinity of the ponds. The remaining ponds and ditches are



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Figure 4.3-7. Temporary ponds and ditches, including ephemeral streams, on the Hanford Site.

shown in Figure 4.3-7. Of the five remaining sites in the 200 West Area, only the West Powerhouse Pond will remain active after June 1995. Of the six remaining sites in the 200 East Area, only the East Powerhouse Ditch and the 216-B-3C Pond will remain active after FY94.

4.3.3 Threatened and Endangered Species

Threatened and endangered plants and animals identified on the Hanford Site, as listed by the federal government (50 CFR 17) and Washington State (Washington Natural Heritage Program 1994), are shown in Table 4.3-7. No plants or mammals on the federal list of Endangered and Threatened Wildlife and Plants (50 CFR 17) are known to occur on the Hanford Site. There are, however, several species of both plants and animals that are under consideration for formal listing by the federal government and Washington State.

The sagebrush habitat is considered priority habitat by Washington because of its relative scarcity in the state, and because of its requirement as nesting/breeding habitat by several state and federal species of concern.

Table 4.3-7. Threatened (T) and endangered (E) species identified on the Hanford Site.

<u>Common Name</u>	<u>Scientific Name</u>	<u>Federal</u>	<u>State</u>
Plants			
Columbia milk-vetch	<i>Astragalus columbianus</i>		T
Columbia yellowcress	<i>Rorippa columbiae</i>		E
Dwarf evening (desert) primrose	<i>Oenothera pygmaea</i>		T
Hoover's desert parsley	<i>Lomatium tuberosum</i>		T
Northern wormwood ^(a)	<i>Artemisia campestris borealis</i> var. <i>wormskioldii</i>		E
Birds			
Aleutian Canada goose ^(b)	<i>Branta canadensis leucopareia</i>	T	E
Peregrine falcon ^(b)	<i>Falco peregrinus</i>	E	E
Bald eagle	<i>Haliaeetus leucocephalus</i>	T	T
White pelican	<i>Pelecanus erythrorhynchos</i>		E
Sandhill crane	<i>Grus canadensis</i>		E
Ferruginous hawk	<i>Buteo regalis</i>		T
Mammals			
Pygmy rabbit ^(a)	<i>Brachylagus idahoensis</i>		E

(a) Probably not currently occurring on the site.

(b) Incidental occurrence.

Plants

Five species of plants are included in the Washington State listing (Washington Natural Heritage Program: Columbia milk-vetch (*Astragalus columbianus*), Dwarf evening primrose (*Oenothera pygmaea*), and Hoover's desert parsley (*Lomatium tuberosum*) are listed as threatened; and Columbia yellowcress (*Rorippa columbiae*) and northern wormwood (*Artemisia campestris* ssp. *borealis* var. *wormskioldii*) are designated endangered. Columbia milk-vetch occurs on dry-land benches along the Columbia River in the vicinity of Priest Rapids Dam, Midway, and Vernita; it also has been found atop Umtanum Ridge and in Cold Creek Valley near the present vineyards. Dwarf evening primrose has been found on mechanically disturbed areas, i.e., the gravel pit near the Wye Barricade. Hoover's desert parsley grows on steep talus slopes in the vicinity of Priest Rapids Dam, Midway, and Vernita. Yellowcress occurs in the wetted zone of the water's edge along the Columbia River. Northern wormwood is known to occur near Beverly and could inhabit the northern shoreline of the Columbia River across from the 100 Areas.

Animals

The federal government lists the Aleutian Canada goose (*Branta canadensis leucopareia*) and the bald eagle (*Haliaeetus leucocephalus*) as threatened and the peregrine falcon (*Falco peregrinus*) as endangered. The state of Washington lists, in addition to the peregrine falcon, the Aleutian Canada goose, bald eagle, white pelican (*Pelecanus erythrorhynchos*), and sandhill crane (*Grus canadensis*) as endangered and the ferruginous hawk (*Buteo regalis*) as threatened. The peregrine falcon is a casual migrant to the Hanford Site and does not nest here. The Oregon silverspot butterfly (*Speyeria zerone hippolyta*) has recently been classified as a threatened species by both state and federal governments. The bald eagle is a regular winter resident and forages on dead salmon and waterfowl along the Columbia River; it does not nest on the Hanford Site, although it has attempted to for the past several years. Access controls are in place along the river at certain times of the year. Washington State Bald Eagle Protection Rules were issued in 1986 (WAC-232-12-292). DOE is currently developing their management plan (Fitzner and Weiss 1992) to mitigate eagle disturbance. The Endangered Species Act of 1973 will also require Section 7 consultation when any action is taken that may destroy, adversely modify, or jeopardize the existence of bald eagle or other endangered species' habitat. An increased use of power poles for nesting sites by the ferruginous hawk on the Hanford Site has been noted.

Table 4.3-8 lists the designated candidate species under consideration for possible addition to the threatened or endangered list. Candidate species must be treated as though they are threatened or endangered for EISs prepared for Hanford Site actions.

Table 4.3-9 lists Washington State plant species that are of concern and are presently listed as sensitive or are in one of three monitor groups (Washington Natural Heritage Program 1994).

Table 4.3-8. Candidate species to the threatened or endangered list.

Common Name	Scientific Name	Federal ^(a)	State
Molluscs			
Shortfaced lanx	<i>Fisherola (= Lanx) nuttalli</i>	X ^(C3)	X
Columbia pebble snail	<i>Fluminicola</i> (= <i>Lithoglyphus</i>) <i>columbiana</i>	X ^(C2)	X
Birds			
Common loon	<i>Gavia immer</i>		X
Swainson's hawk	<i>Buteo swainsoni</i>		X
Ferruginous hawk	<i>Buteo regalis</i>	X ^(C2)	
Western sage grouse ^(b)	<i>Centrocercus urophasianus</i> <i>phaeos</i>	X ^(C2)	X
Sage sparrow	<i>Amphispiza belli</i>		X
Burrowing owl	<i>Athene cunicularia</i>		X
Loggerhead shrike	<i>Lanius ludovicianus</i>	X ^(C2)	X
Northern goshawk ^(b)	<i>Accipiter gentilis</i>	X ^(C2)	X
Lewis' woodpecker ^(b)	<i>Melanerpes lewis</i>		X
Long-billed curlew	<i>Numenius americanus</i>	X ^(C3)	
Sage thrasher	<i>Oreoscoptes montanus</i>		X
Flammulated owl ^(b)	<i>Otus flammeolus</i>		X
Western bluebird ^(b)	<i>Sialia mexicana</i>		X
Golden eagle	<i>Aquila chrysaetos</i>		X
Black tern ^(b)	<i>Chlidonius niger</i>	X ^(C2)	
Trumpeter swan ^(b)	<i>Cygnus columbianus</i>	X ^(C2)	
Insects			
Columbia River tiger beetle ^(c)	<i>Cinindela colubica</i>		X
Reptiles			
Striped whipsnake	<i>Masticophis taeniatus</i>		X
Mammals			
Merriam's shrew	<i>Sorex merriami</i>		X
Pacific western big-eared bat ^(c)	<i>Plecotus townsendii</i> <i>townsendii</i>	X ^(C2)	X
Pygmy rabbit ^(c)	<i>Brachylagus idahoensis</i>	X ^(C2)	
Plants			
Columbia milk-vetch	<i>Astragalus columbianus</i>	X ^(C1)	
Columbia yellowcress	<i>Rorippa columbiae</i>	X ^(C2)	
Hoover's desert parsley	<i>Lomatium tuberosum</i>	X ^(C2)	
Northern wormwood ^(c)	<i>Artemisia campestris</i> <i>borealis</i> var. <i>wormskioldii</i>	X ^(C1)	

(a) Abbreviations:

- C1 = Taxa for which the Service has enough substantial information on biological vulnerability to support proposals to list them as endangered or threatened species. Listing is anticipated but has temporarily been precluded by other listing activity.
- C2 = Taxa for which current information indicates that proposing to list as endangered or threatened is possibly appropriate, but for which conclusive data on biological vulnerability are not available to support listing. The Service will not propose listing unless additional supporting information becomes available.
- C3 = Taxa that were once considered for listing as endangered or threatened, (i.e., in categories 1 or 2) but are no longer current candidates for listing. Such taxa are further subdivided into three categories that indicate why they were removed from consideration.

(b) Species reported, but seldom observed, on the Hanford Site.

(c) Probable, but not observed, on the Hanford Site.

Table 4.3-9. Washington State plant species of concern occurring on the Hanford Site.

<u>Common Name</u>	<u>Scientific Name</u>	<u>Status^(a)</u>
Desert Evening primrose	<i>Oenothera Caespitosa</i>	S
Shining flatsedge	<i>Cyperus rivularis</i>	S
Dense sedge	<i>Carex densa</i>	S
Gray cryptantha	<i>Cryptantha leucophaea</i>	S
Piper's daisy	<i>Erigeron piperianus</i>	S
Southern mudwort	<i>Limosella acaulis</i>	S
False-pimpernel	<i>Lindernia anagallidea</i>	S
Tooth-sepal dodder	<i>Cuscuta denticulata</i>	M1
Thompson's sandwort	<i>Arenaria franklinii</i> v. <i>thompsonii</i>	M2
Bristly cryptantha	<i>Cryptantha interrupta</i>	M2
Robinson's onion	<i>Allium robinsonii</i>	M3
Columbia River mugwort	<i>Artemisia lindleyana</i>	M3
Stalked-pod milkvetch	<i>Astragalus sclerocarpus</i>	M3
Medic milkvetch	<i>Astragalus speirocarpus</i>	M3
Crouching milkvetch	<i>Astragalus succumbens</i>	M3
Rosy balsamroot	<i>Balsamorhiza rosea</i>	M3
Palouse thistle	<i>Cirsium brevifolium</i>	M3
Smooth cliffbrake	<i>Pellaea glabella</i>	M3
Fuzzy-beard tongue penstemon	<i>Penstemon eriantherus</i>	M3
Squill onion	<i>Allium scillioides</i>	M3

The following species may inhabit the Hanford Site, but have not been recently collected, and the known collections are questionable in terms of location and/or identification.

Palouse milkvetch *Astragalus arrectus* S

Few-flowered blue-eyed Mary *Collinsia sparsiflora* S

Coyote tobacco *Nicotiana attenuata* S

(a) Abbreviations: S = sensitive, i.e., taxa vulnerable or declining, and could become endangered or threatened without active management or removal of threats; M1 = Monitor group 1. Taxa for which there are insufficient data to support listing as threatened, endangered, or sensitive. M2 = Monitor group 2, i.e., taxa with unresolved taxonomic questions. M3 = Monitor group 3, i.e., taxa that are more abundant and/or less threatened than previously assumed.

4.3.4 Wildlife Refuges

Several national and state wildlife refuges are located on or adjacent to the Hanford Site. These refuges are shown in Figure 4.3-5.

4.3.5 100 Areas

For most purposes, the ecological characterization of the Hanford Site can be used. Some unique characteristics of the 100 Areas follow.

Terrestrial Ecology

Cheatgrass is prevalent because of the extensive perturbation of soils in these areas. The characteristic communities found are cheatgrass-tumble mustard, sagebrush/cheatgrass, or Sandberg's bluegrass, sagebrush-bitterbrush/cheatgrass, and willow-riparian vegetation near the Columbia River shoreline.

The insects, reptiles, amphibians, birds, and mammals found in this area are the same as those common to the Hanford Site, with the following exceptions. California quail and Chinese ring-necked pheasants are more likely to be found near the Columbia River, and several mammals, such as raccoons, beavers, and porcupines, are more likely to be present near water.

Aquatic Ecology

The major aquatic site related to the 100 Areas is, of course, the Columbia River, which flows past each of the reactor sites. The ecology of the Columbia River is presented in the Hanford Site section.

Threatened and Endangered Species

Three of the plants listed by the state of Washington occur in proximity to the Columbia River and could be found in the 100 Areas: Columbia milk-vetch (*Astragalus columbianus* Barneby), listed as threatened; and Columbia yellowcress (*Rorippa columbiae* Suksd.) and northern wormwood (*Artemisia campestris borealis* var. *wormskioldi*), designated endangered. Two candidate molluscs could also occur in this area, the shortfaced lanx (*Fisherola nuttalli*) and Columbia pebble snail (*Fluminicola columbiana*).

4.3.6 200 Areas

The description of the ecological characteristics of the Hanford Site can be used for most work pertaining to the 200 Areas. Unique features are described here.

Terrestrial Ecology

Most plant communities occurring on the Hanford Site can be found near the 200 Areas, or at least on the 200-Area Plateau. The sagebrush/cheatgrass or Sandberg's bluegrass community is perhaps the most common in the area.

The insects, birds, reptiles, amphibians, and mammals common to the Hanford Site can be found in this area.

Aquatic Ecology

The aquatic sites found in the 200 Areas are the temporary water bodies described under the general Hanford Site section and are those associated with waste-disposal practices. No other unique sites are found in this area.

4.3.7 300 Area

The 300 Area has no unique terrestrial or aquatic ecological characteristics. It most closely resembles the 100 Areas because of its proximity to the Columbia River.

The ant populations of the Hanford 300-Area waste burial grounds were characterized and their habits described by Fitzner et al. (1979). Species encountered were *Solenopsis molesta*, *Pogonomyrmex owyheeii*, *Formica subpolita*, and *Formica manni*. Ants are of some concern in radioactive waste management because they can excavate soil to a depth of several meters. Thus, buried waste can be transported from shallow waste burial sites to the surface.

4.4 Historical, Archaeological, and Cultural Resources

The Hanford Site is known to be rich in cultural resources. It contains numerous well-preserved archaeological sites representing both prehistoric and historical periods and is still thought of as a homeland by many Indian people. Historical period resources include sites, buildings, and structures from the pre-Hanford site, Manhattan Project, and Cold War eras. Management of Hanford's cultural resources follows the Hanford Cultural Resources Management Plan (Chatters 1989) and is conducted by the Hanford Cultural Resources Laboratory (HCRL) of PNL.

4.4.1 Archaeological Resources

People have inhabited the Middle Columbia River region since the end of the glacial period. More than 10,000 years of prehistoric human activity in this largely arid environment have left extensive archaeological deposits along the river shores (Leonhardy and Rice 1970; Greengo 1982; Chatters 1989). Well-watered areas inland from the river show evidence of concentrated human activity (Chatters 1982, 1989; Daugherty 1952; Greene 1975; Leonhardy and Rice 1970; Rice 1980), and recent surveys have indicated extensive, although dispersed, use of arid lowlands for hunting. Graves are common in various settings, and spirit quest monuments are still found on high, rocky summits of the mountains and buttes (Rice 1968a). Throughout most of the region, hydroelectric development, agricultural activities, and domestic and industrial construction have destroyed or covered the majority of these deposits. Amateur artifact collectors have had an immeasurable impact on what remains. By virtue of their inclusion in the Hanford Site from which the public is restricted, archaeological deposits found in the Hanford Reach of the Columbia River and on adjacent plateaus and mountains have been spared some of the disturbances that have befallen other sites. The Hanford Site is thus a de facto reserve of archaeological information of the kind and quality that have been lost elsewhere in the region.

There are currently 248 prehistoric archaeological sites recorded in the files of the HCRL. Forty-seven of these sites are included on the National Register of Historic Places (National Register): two as single sites and the remainder in seven archaeological districts (Table 4.4-1). In addition, a nomination has been prepared for one cultural district (Gable

Mountain/Gable Butte), and renomination for two additional archaeological districts is pending (Wahluke, Coyote Rapids) (Table 4.4-2). Four other sites are considered eligible for the National Register. Archaeological sites include remains of numerous pithouse villages, various types of open campsites, and cemeteries (Rice 1968a, 1980), spirit quest monuments (rock cairns), hunting camps, game drive complexes and quarries in mountains and rocky bluffs (Rice 1968b), hunting/kill sites in lowland stabilized dunes, and small temporary camps near perennial sources of water located away from the river (Rice 1968b).

Many recorded sites were found during four archaeological reconnaissance projects conducted between 1926 and 1968 (Krieger 1928; Drucker 1948; Rice 1968a,b). Systematic archaeological surveys conducted from the middle 1980s through 1994 are responsible for the remainder (Chatters 1989; Chatters and Cadoret 1990; Chatters and Gard 1992; Chatters et al. 1990, 1991, 1992; Last et al. 1993). Little excavation has been conducted at any of the sites, and the Mid-Columbia Archaeological Society (MCAS) has done most of that work. They have conducted minor test excavations at several sites on the river banks and islands (Rice 1980) and a larger scale test at site 45BN157 (Den Beste and Den Beste 1976). The University of Idaho also excavated a portion of site 45BN179 (Rice 1980) and collaborated with the MCAS on its other work. Test excavations have been conducted by the HCRL at the Wahluke (45GR306), Vernita Bridge (45BN90), and Tsulim (45BN412) sites and at 45BN446; 45BN423, 45BN163, 45BN432, and 45BN433; results support assessments of significance for those sites. Most archaeological survey and reconnaissance activity has concentrated on islands and on a strip of land <400 m wide on either side of the river (Rice 1980). During his reconnaissance of the Hanford Site in 1968, Rice (1968b) inspected portions of Gable Mountain, Gable Butte, Snively Canyon, Rattlesnake Mountain, and Rattlesnake Springs, but gave little attention to other areas. Rice inspected additional portions of Gable Mountain and part of Gable Butte in the late 1980s (Rice 1987). Some reconnaissance of the Basalt Waste Isolation Project Reference Repository Location (RRL; Rice 1984), a proposed land exchange in T22N, R27E, Section 33 (Rice 1981), and three narrow transportation and utility corridors (ERTEC 1982; Morgan 1981; Smith et al. 1977) were also conducted. The 100 Areas were surveyed from 1991 through 1993, revealing a large number of new archaeological sites (Chatters et al. 1992; Wright 1993). To date, approximately 6% of the Hanford Site has been surveyed. Cultural resource reviews are conducted when projects are proposed for areas not previously reviewed. About 100 to 120 reviews were conducted annually through 1991, and this figure rose to more than 400 reviews during 1993. These reviews ensure that known historic and archaeological sites are not adversely impacted by proposed projects, especially if any site is found to be eligible for listing on the National Register. Such a review becomes especially important if the potential exists for the discovery of human remains. Such a discovery would likely result in a project stop-work order as required by the Native American Graves Repatriation and Protection Act.

4.4.2 Native American Cultural Resources

In prehistoric and early historic times, the Hanford Reach of the Columbia River was heavily populated by Indian people of various tribal affiliations. The Chamnapum band of

Table 4.4-1. Historic properties on the Hanford Site listed on the National Register of Historic Places and the archaeological sites within them.

Property Name	Site(s) Included
Wooded Island A.D. ^(a)	45BN107 through 45BN112, 45BN168
Savage Island A.D.	45BN116 through 45BN119, 45FR257 through 45FR262
Hanford Island Site	45BN121
Hanford North A.D.	45BN124 through 45BN133, 45BN134, 45BN178
Locke Island A.D.	45BN137 through 45BN140, 45BN176
	45GR302 through 45GR305
Ryegrass A.D.	45BN149 through 45BN157
Paris Site	45GR137
Rattlesnake Springs A.D.	45BN170, 45BN171
Snively Canyon A.D.	45BN172, 45BN173
100-B Reactor	NA ^(a)

(a) A.D. indicates archaeological district (this table). NA, not applicable.

Table 4.4-2. Historic properties on the Hanford Site nominated, or prepared for nomination, to the National Register of Historic Places.

Property Name ^(a,b)	Site(s) Included
Gable Mountain/Gable Butte A.D. ^(a)	45BN348 through 45BN352, 45BN354 through 45BN363, 45BN402 through 45BN410; 45BN447
Wahluke A.D. ^(b)	45BN141 through 45BN147; 45GR306
Coyote Rapids A.D. ^(b)	45BN152; 45GR312 through 45GR314
	105-B Building

(a) Nomination forms have been prepared. A.D. = archeological district (this table).

(b) Nominated; rejected because of lack of documentation; renomination is pending.

the Yakama tribe dwelt along the Columbia River from south of Richland upstream to Vantage (Relander 1956; Spier 1936). Some of their descendants still live nearby at Priest Rapids, and others have been incorporated into the Yakama and Umatilla reservations. Palus people, who lived on the lower Snake River, joined the Wanapum and Chamnapum to fish the Hanford Reach and some inhabited the river's east bank (Relander 1956; Trafzer and Scheuerman 1986). Walla Walla and Umatilla people also made periodic visits to the area to fish. These peoples retain traditional secular and religious ties to the region, and there are many, young and old alike, who have knowledge of the ceremonies and lifeways of their aboriginal culture. The Washane, or Seven Drums religion, which has ancient roots and had its start on the Hanford Site, is still practiced by many people on the Yakama, Umatilla, Warm Springs, and Nez Perce reservations. Native plant and animal foods, some of which can be found on the Hanford Site, are used in the ceremonies performed by sect members. Tribal members have expressed an interest in renewing their

use of these resources in accordance with the Treaties of 1855, and the DOE is assisting them in this effort. Certain landmarks, especially Rattlesnake Mountain, Gable Mountain, Gable Butte, Goose Egg Hill, and various sites along and including the Columbia River, are sacred to them. These people also consider the many cemeteries along the river and on the Hanford Site to be sacred.

4.4.3 Historic Period Resources

The first Euro-Americans who came into this region were Lewis and Clark, who traveled along the Columbia and Snake rivers during their 1803-1806 exploration of the Louisiana Territory. They were followed by fur trappers, who also passed through on their way to more productive lands up and down river and across the Columbia Basin. It was not until the 1860s that merchants set up stores, a freight depot, and the White Bluffs Ferry on the Hanford Reach. Chinese miners began to work the gravel bars for gold. Cattle ranches opened in the 1880s and farmers soon followed. Several small, thriving towns, including Hanford, White Bluffs, and Ringold, grew up along the riverbanks in the early twentieth century. Other ferries were established at Wahluke and Richmond. The towns and nearly all other structures were razed after the U.S. Government acquired the land for the Hanford Engineer Works in 1943 (Chatters 1989; ERTEC 1981; Rice 1980).

A total of 202 historic archaeological sites and numerous historic properties have been recorded. Properties from the pre-Hanford Site era include the Hanford Irrigation and Power Company's pumping plant at Coyote Rapids, the Hanford Irrigation Ditch, the Hanford townsite, Wahluke Ferry, the White Bluffs townsite, the Richmond Ferry, Arrow-smith townsite, a cabin at East White Bluffs ferry landing, the White Bluffs road, the Hanford High School, and Bruggeman's fruit warehouse at Riverland (Rice 1980). Historic archaeological sites including the East White Bluffs townsite and associated ferry landings, and an assortment of trash scatters, homesteads, corrals, and dumps, have been recorded by the HCRL since 1987. ERTEC Northwest was responsible for minor test excavations at some of the historic sites, including the Hanford townsite. Resources from the pre-Hanford Site period are scattered over the entire Hanford Site and include numerous areas of gold mine tailings along riverbanks of the Columbia and the remains of homesteads, farm fields, ranches, and irrigation-related features.

Historic resources documented from the Manhattan Project and Cold War eras include buildings and structures primarily found in the 100, 200 and 300 Areas. The most important of these are the defense reactors and plutonium-production and processing facilities that now dominate the site. The first reactors (100-B, 100-D, and 100-F) were constructed in 1943 as part of the Manhattan Project. Plutonium for the first atomic explosion and the bomb that destroyed Nagasaki to end World War II were produced in the 100-B Facility. Additional reactors and processing facilities were constructed after World War II, during the Cold War. All reactor containment buildings still stand, although many ancillary structures have been removed. The 100-B Reactor has been listed on the National Register of Historic Places. Other Manhattan Project facilities have not been evaluated. Until a full evaluation of all Manhattan Project and Cold War buildings and facilities has been conducted, statements about their National Register status cannot be made. Individual buildings will be evaluated once they are scheduled for major remodeling

or demolition. Long-range plans for the evaluation of historic buildings include the preparation of a Multiple Property Document to assist in the National Register evaluation process.

4.4.4 100 Areas

The 100 Areas were surveyed during 1991, 1992, and 1993 for cultural resources. Much of the surface area within the 100 Area Operable Units has been disturbed by the industrial activities that have taken place during the past 40 years. However, numerous historic and prehistoric archaeological sites have been found, and many are potentially eligible for the National Register. Most historic period buildings and structures have yet to be evaluated for their National Register eligibility. Evaluations will occur once individual buildings are scheduled for major remodeling or demolition.

- **100-B and 100-C Areas.** The 100-B Reactor is listed as a National Historic Civil Engineering Landmark and is listed on the National Register of Historic Places. Additional buildings from the Manhattan Project and early Cold War era stand in this area. Historic and prehistoric archaeological resources exist in the vicinity of 100-B and 100-C Areas, at least on the basis of the level of reconnaissance that has been done there. Only three sites can be identified from area literature (Rice 1968a, 1980). All lie partially within the 100-B and 100-C Areas. A fourth archaeological site and the remains of the early 20th-century town of Haven lie on the opposite bank of the Columbia River. The archaeological site appears to contain artifact deposits about 3500-2500 years old but has not been tested. One archaeological site near 100B/C (45BN446) was evaluated in 1994 and the state historic preservation officer has determined that it is eligible for listing on the National Register. The other two sites have not been tested to determine National Register eligibility. Numerous sites related to hunting and religious activities are located at the west end of Gable Butte, due south of the 100-B and 100-C Areas. These sites are part of the proposed Gable Mountain/Gable Butte Traditional Cultural Property nomination. Test excavations conducted in 1991 at one hunting site in Gable Butte revealed large quantities of deer and mountain sheep bone and projectile points dating from 500 and 1500 years old.
- **100-D and 100-DR Areas.** Thirty-six known archaeological sites lie within 2 km (1.2 mi) of the areas, three on the left (opposite) bank of the river and thirty-three on the right bank. Three sites, 45GR306A, 45GR307, and 45GR308 are open campsites of unknown age (Rice 1968a). None has been considered eligible for the National Register of Historic Places, but no record exists of a formal evaluation of the sites having been completed. Sites 45BN439 and 45BN459 are occupation sites of undetermined age; sites 45BN442, 45BN443, and 45BN444 are cairns; and 45BN461 is a fishing site. The remaining sites were recorded in 1992 and 1993 and represent early Euro-American settlement activities. None of these sites has been evaluated for eligibility for the National Register. The townsite of Wahluke, which was at the landing of a ferry of the same name, is also situated on the river's left bank. The midchannel island off the 100-D and 100-DR areas may be the one called Watklumpt by the Wanapum Indians (Relander 1956). Many buildings in this area were built for the Manhattan Project and all must be evaluated for National Register eligibility before alteration or demolition.

- **100-F Area.** The 100-F Area is situated on a segment of the Columbia River that contains a multitude of cultural sites. According to Relander (1956), camps and villages of the Wanapum people extended from the Hanford townsite upstream to the White Bluffs townsite. Among those were the villages of *Walwalkh*, *Tohoke*, and *Tacht* and the sites of *Wyone* and *Y'yownow*, which were fishing and fish processing locations, respectively. *Tacht* (the name for White Bluffs) was one of the principal sedentary villages of the Wanapum and was used until 1943. Four prehistoric archaeological sites, including one dating to 4000-9000 years old, were found in the 100-F-Area during 1991 surveys. Two of these sites (45BN432 and 45BN433) have been evaluated for their National Register eligibility; two have not been evaluated (45BN431 and 45BN435). There are six other prehistoric archaeological sites within 2 km (1.2 mi) of this area. They are all identified as open camps, except for one, which contains housepits. Site 45FR264 appears to contain artifact deposits extending back to at least 6000 years B.P. Site 45BN178 is included in the Hanford North Archaeological District, which is listed on the National Register of Historic Places. One additional site, 45BN128, is a cemetery.

The principal historic site in the vicinity is the East White Bluffs ferry landing and townsite (45FR314h), which has been considered for nomination to the National Register of Historic Places. It is located on the east bank of the Columbia River and is coterminous with 45FR266. The site was the upriver terminus of shipping during the early- and mid-19th century. It was at this point that supplies for trappers, traders, and miners were off-loaded, and commodities from the interior were transferred from pack trains and wagons to river boats. The first store and ferry of the mid-Columbia region were located there (ERTEC 1981). A log cabin, thought by some to have been a black-smith shop in the mid-19th century, still stands there. Test excavations were conducted at the cabin by the University of Idaho, and the structure has been recorded according to standards of the Historic American Buildings Survey (Rice 1976). During 1991 surveys, four historic 20th-century archaeological sites (H-11, H-12, H-13, and H-14), consisting of household debris, were found inside the 100-F Area proper. Two Manhattan Project buildings that have not been evaluated remain in the 100-F Area. These buildings will be evaluated once they are scheduled for major remodeling or demolition.

- **100-H Area.** Since construction of dams elsewhere in the Columbia River system, this is the most archaeologically rich area in the western Columbia Plateau. There are 10 recorded archaeological sites within 2 km (1.2 mi) of the area, including 45BN138 through 45BN141, and 45GR302 (a,b,c) through 45GR305. These include two historic Wanapum cemeteries, six camps (one associated with a cemetery), and three housepit villages. The largest village, 45GR302a, contains more than 100 housepits and numerous storage caches. It appears to have been occupied from 2500 years ago to historic times (Rice 1968a). All these sites are included in the Locke Island Archaeological District, listed in the National Register of Historic Places. Locke Island itself was known to the Wanapum Indians as *K'watch* (Relander 1956). The historic village of *Tacht*, which was still used until establishment of the Hanford Site, was located 1 km (0.6 mi) south of the reactor facility. Several living members of the Wanapum, Palus,

and Yakama tribes recall residing there. Surveys conducted in 1992 by the HCRL showed that this site had been destroyed by soil borrowing, probably in the 1940s or 1950s.

Fourteen historic sites in the vicinity were recorded during 1992 and 1993 and include numerous farmsteads, historic dumps, and military encampments. These areas were created in the 20th century. None have been evaluated for eligibility to the National Register of Historic places.

- **100-K Area.** Events took place at this locality that were of great significance to Indian people in the interior Northwest. It was here, in the mid-19th century, that Smohalla, Prophet of the Wanapum people, held the first *Washat*, the dance ceremony that has become central to the Seven Drums or Dreamer religion (Relander 1956). As a result of Smohalla's personal abilities, the religion spread to many neighboring tribes and is now practiced in some form by members of the Colville, Nez Perce, Umatilla, Wanapum, Warm Springs, and Yakama tribes. The site of this historic event was the south bank of the Columbia River near *Moon*, or Water Swirl Place, which we call Coyote Rapids.

Archaeological survey of the 100-K Area in 1991 revealed five previously unrecorded archaeological sites. Two sites date to the Cascade Phase (9000-4000 years ago). A large fish-processing camp, represented by fire-broken rock mingled with river gravels, extends downstream from Coyote Rapids. These areas have yet to be evaluated. More importantly, a recent (one or two centuries old) group of pit houses with associated longhouse and sweat lodge was identified and may have been the site of Smohalla's first *Washat* dance. This site has been evaluated and is considered to be eligible for listing on the National Register. Three other sites, 45GR312, 45GR313, and 45GR314, which compose the Coyote Rapids Archaeological District, are on the opposite bank of the river. This district was nominated to the National Register of Historic Places, but the nomination was rejected in 1976 because of insufficient information. Site 45BN151 is an historic Wanapum cemetery that was probably associated with 45BN423. Historic sites containing the remains of farms litter the area around 100-K; four historic sites and three isolated finds have been recorded as of 1994.

- **100-N Area.** The 100-N Area is situated on an archaeologically rich segment of the Columbia River's shore. Within 2 km (1.2 mi) of the area perimeter are fourteen archaeological sites, including 45BN149, 45BN150, 45BN151, 45BN179, and 45BN180 on the south shore and 45GR309, 45GR310, and 45GR311 on the north shore. Four of these sites are either listed, or considered eligible for inclusion, on the National Register of Historic Places. Sites 45BN149, 45BN150, and 45BN151, which include two pithouse villages and one cemetery, respectively, comprise the Ryegrass Archaeological District. Site 45BN179, once considered for nomination as the Hanford Generating Plant Site, has been found to be part of 45BN149, which is already listed on the National Register (Chatters et al. 1990). Recently recorded sites include 45BN437, 45BN438, 45BN440, 45BN442, and 45BN443. None have been evaluated.

In 1973, Rice (1980) conducted test excavations at 45BN179. During that excavation, which consisted of excavating two trenches and two smaller pits (32 m², ~ 3 ft²), Rice found evidence of habitation during four periods of prehistory. The earliest, undated occupation of the site occurred during the Vantage Phase of the local chronology (Swanson 1962; Nelson 1969) which dates to before 4500 B.P. Small amounts of material, also undated, were attributable to the Frenchman Springs Phase (4500-2500 B.P.). Above that were dense artifact deposits and remains of pithouses dating after 1862 B.P., which Rice attributed to the Cayuse Phase (2000 B.P., to historic times). Capping the sequence of deposits was debris left by Wanapum Indian people during their historic occupation of the site. No excavations have been conducted in other sites within the Ryegrass Archaeological District.

Extant knowledge about the archaeology of the 100-N Area is based largely on reconnaissance-level archaeological surveys (Rice 1968b; see also Rice 1980), which do not purport to produce complete inventories of the areas covered. Only the vicinity of the Hanford Generating Plant has been surveyed intensively for archaeological resources (Rice 1980).

Three areas near the 100-N Area are known to have been of some importance to the Wanapum. The knobs and kettles south and east of the area were called *Moolimooli*, which means Little Stacked Hills. Coyote Rapids, which is a short distance upstream, was called *Moon*, or Water Swirl Place. Gable Mountain (called *Nookshai* or Otter) and Gable Butte, which lie to the south of the river, are sacred mountains where youths would go on overnight vigils seeking guardian spirits (Relander 1956). No sites of religious importance are known to exist within the 100-N compound but may exist nearby.

The most common evidence of historic activity now found near the 100-N Area consists of gold mine tailings on riverbanks and historic archaeological sites where homesteads once stood. Few of these vestiges of the early years remain. The significance of 100N Area buildings, their role in the Cold War, and their potential eligibility for listing on the National Register have not been determined. Individual buildings will be evaluated as they are scheduled for major remodeling or demolition.

4.4.5 200 Areas

An archaeological survey has been conducted of all undeveloped portions of the 200-East Area and a portion of the 200-West Area. Additional surveys of undeveloped portions of the 200 West Area are required. The only evaluated historic site is the old White Bluffs freight road that crosses diagonally through the 200-West Area. The road, which was formerly an Indian trail, has been in continuous use since antiquity and has played a role in Euro-American immigration, development, agriculture, and the Hanford Site operations. This property has been determined by the State Historic Preservation Officer to be eligible for the National Register of Historic Places, although the segment that passes through the 200 West Area is considered to be a noncontributing element. The nomination of this historic property is pending. A 100-m (328-ft) easement has been created to

protect the road from uncontrolled disturbance. Historic period buildings from the Manhattan Project and Cold War eras that have not been evaluated for National Register eligibility are located in both the 200-East and 200-West Areas.

4.4.6 300 Area

Most of the 300 Area has been highly disturbed by industrial activities. Several archaeological surveys of the 300 Area have been conducted (Cleveland et al. 1976; Drucker 1948; Rice 1968a; Thomas 1983; Morgan 1981), as well as several smaller surveys conducted by the Hanford Cultural Resources Laboratory (HCRL) for specific DOE-RL projects. Five recorded archaeological sites are located at least partially within the 300 Area; however, many more may be located in subsurface deposits. The first four sites listed are prehistoric, including camp sites and housepits. One is a historic trash scatter. None of the sites within the 300 Area have been tested for subsurface deposits, nor have they been evaluated for eligibility for the National Register.

Twenty-one archaeological sites and three isolated artifacts have been recorded within 2 km of the 300 Area perimeter. Nine of these sites are historic, eleven are prehistoric, and one contains both historic and prehistoric components. The historic sites consist of debris scatters and road beds associated with farmsteads. The prehistoric sites are similar to those found within the 300 Area. Much of the area in the 2 km perimeter of the 300 Area has not been surveyed previously; many more sites may exist in this area.

Many buildings constructed during the Manhattan Project and Cold War era are located in the 300 Area. These buildings are currently evaluated for eligibility for the National Register when they are scheduled for major remodeling or demolition.

One documented locality which has great importance to the historic Wanapum tribe is located near the 300 Area. *Sekema*, a favorite place for taking salmon that had already spawned, was located some 10 km (6 mi) north of Richland (Relander 1956), which would place it 2 to 3 km (1.2 to 1.8 mi) north of the 300 Area boundary. However, because Relander's descriptions of geographic locations are only approximate, it is possible that *Sekema* corresponds to any or all of the sites in or around the 300 Area listed previously.

4.4.7 400 Area

Most of the 400 Area has been so disrupted by construction activities that archaeologists surveying the site in 1978 were able to find only 30 acres that were undisturbed (Rice et al. 1978). They found no cultural resources in that small area. No sites are known to be located within 2 km of the 400 Area.

4.4.8 1100 Area

Historic cultural resources have been identified in or near the 1100 Area. These include remains of homesteads and agricultural facilities predating the Hanford Site. No mention is

made by Relander (1956) of any location important to the Wanapum Indians. All of these sites will be evaluated for National Register eligibility before the start of proposed projects that could adversely impact them.

4.4.9 3000 Area

Archaeological surveys of the 3000 Area have been confined to a narrow strip along the Columbia River (Cleveland et al. 1976; Drucker 1948; Rice 1968a; Thoms 1983). Twelve sites are within 2 km of the area perimeter, including 45BN267 located inland; 45BN26; 45BN27, 45BN28, and 45BN104 located on the west bank; 45BN43, 45BN44, 45BN101, 45BN102, 45BN103, and 45BN192 located on an island; and 45FR308 located on the east bank. None of these sites has been evaluated for National Register eligibility. Thoms (1983) recommended that these sites and others in the Tri-Cities area should be incorporated into an archaeological district, but a nomination has not been made. Site types represented include one housepit/occupation site, six open camp/fishing stations, three shell middens, and one human grave.

No historic sites have been recorded for this area, but homesteads and remnants of the North Richland townsite and buildings associated with Camp Hanford from the early 1950s are found there.

4.5 Socioeconomics

Activity on the Hanford Site plays a dominant role in the socioeconomics of the Tri-Cities (Richland, Pasco, and Kennewick) and other parts of Benton and Franklin counties. The agricultural community also has a significant effect on the local economy. Any major changes in Hanford activity would potentially most affect the Tri-Cities and other areas of Benton and Franklin Counties.

4.5.1 Employment and Income

Three major sectors have been the principal driving forces of the economy in the Tri-Cities since the early 1970s: 1) DOE and its contractors operating the Hanford Site; 2) Washington Public Power Supply System in its construction and operation of nuclear power plants; and 3) the agricultural community, including a substantial food-processing component. With the exception of a minor amount of agricultural commodities sold to local-area consumers, the goods and services produced by these sectors are exported outside the Tri-Cities. In addition to the direct employment and payrolls, these major sectors also support a sizable number of jobs in the local economy through their procurement of equipment, supplies, and business services.

In addition to these three major employment sectors, three other components can be readily identified as contributors to the economic base of the Tri-Cities economy. The first of these, loosely termed "other major employers," includes five such employers: 1) Siemens Nuclear Power Corporation in North Richland, 2) Sandvik Special Metals in Kenne-

wick, 3) Boise-Cascade in Wallula, 4) Burlington Northern Railroad, and 5) Iowa Beef Processors. The second component is tourism. The Tri-Cities area has increased its convention business substantially in recent years, in addition to business generated by travel for recreation. The final component in the economic base relates to the local purchasing power generated not from current employees but from retired former employees. Government transfer payments in the form of pension benefits constitute a significant proportion of total spendable income in the local economy.

DOE Contractors (Hanford). Hanford continued to dominate the local employment picture with almost one-quarter of the total nonagricultural jobs in Benton and Franklin counties in 1993 (17,700 of 70,700). Hanford's payroll has a widespread impact on the Tri-Cities and state economy in addition to providing direct employment. These effects are further described in Subsection 4.5.2.

Washington Public Power Supply System. Although activity related to nuclear power construction ceased with the completion of the WNP-2 reactor in 1983, the Washington Public Power Supply System continues to be a major employer in the Tri-Cities area. Headquarters personnel based in Richland oversee the operation of one generating facility and perform a variety of functions related to two mothballed nuclear plants and one standby generating facility. In 1993, the Washington Public Power Supply System headquarters employment was more than 1700 workers. Washington Public Power Supply System activities generated a payroll of approximately \$80.4 million in the Tri-Cities during the year.

Agriculture. In 1993, agricultural activities in Benton and Franklin counties were responsible for approximately 12,043 jobs, or 17% of the area's total employment. According to the U.S. Department of Commerce's Regional Economic Information System, about 2280 people were classified as farm proprietors in 1991. Farm proprietors' income from this same source was estimated to be \$79 million in the same year.

Crop and livestock production in the bicounty area generated about over 7000 wage and salary jobs in 1990, as represented by the number of employees covered by unemployment insurance. The presence of seasonal farm workers would increase the total number of farm workers. Apart from the difficulty of obtaining reliable information on the number of seasonal workers, however, there is the question of how much of these earnings are actually spent in the local area. For this analysis, we assumed that the impact of seasonal workers on the local economy is sufficiently small to be safely ignored.

The area's farms and ranches generate a sizable number of jobs in supporting activities such as agricultural services (e.g., application of pesticides and fertilizers, irrigation system development, etc.) and sales of farm supplies and equipment. These activities, often called "agribusiness," are estimated to employ 900 people.

Although formally classified as a manufacturing activity, food processing is a natural extension of the farm sector. More than 20 food processors in Benton and Franklin counties produce such items as potato products, canned fruits and vegetables, wine, and animal feed.

Other Major Employers. In 1993, other major employers (Siemens Nuclear Power Corporation, Sandvik Special Metals, Iowa Beef Processors, Boise Cascade, and Burlington Northern Railroad) employed approximately 3500 people in Benton and Franklin counties. Although Boise Cascade's Wallula mill lies outside both Benton and Franklin counties, most of its workforce resides in the Tri-Cities.

Tourism. The Tri-Cities Visitors and Convention Bureau reported 229 conventions were held in the Tri-Cities in 1993, with 37,592 attending visitors who spent an estimated \$11.9 million.

A study by the Washington State Tourism Development Division estimated that overall tourism expenditures in the Tri-Cities were roughly \$132.5 M in 1991 and that travel-generated employment in Benton and Franklin counties was about 2230 with an estimated \$25 M in payroll.

Retirees. Although Benton and Franklin counties have a relatively young population (approximately 56% under the age of 35), 16,114 people over the age of 65 resided in Benton and Franklin counties in 1993. The portion of the total population 65 years and older in Benton and Franklin Counties accounts for 9.8% of the total population, slightly below that of the State of Washington (11.6%). This segment of the population supports the local economy on the basis of income received from government transfer payments and pensions, private pension benefits, and prior individual savings.

Although information on private pensions and savings is not available, data are available regarding the magnitude of government transfer payments. The Department of Commerce's Regional Economic Information System has estimated transfer payments by various programs at the county level. A summary of estimated major government pension benefits received by the residents of Benton and Franklin counties in 1991 is shown in Table 4.5-1. About two-thirds of Social Security payments go to retired workers; the remainder are for disability and other payments. The historical importance of government activity in the Tri-Cities area is reflected in the relative magnitude of the government employee pension benefits as compared with total payments.

Table 4.5-1. Government retirement payments in Benton and Franklin Counties, 1991 (millions of dollars).

	<u>Benton County</u>	<u>Franklin County</u>	<u>Total</u>
Social Security (incl. survivors and disability)	114.9	33.6	148.5
Railroad retirement	2.9	4.0	6.9
Federal civilian retirement	11.3	2.8	14.1
Veterans pension and military retirement	15.8	3.4	19.2
State and local employee retirement	<u>22.7</u>	<u>5.6</u>	<u>28.3</u>
	167.6	49.4	217.0

Secondary Sector. The secondary sector consists of all other workers in Benton and Franklin counties. A breakdown of nonagricultural wage and salary workers employed in Benton and Franklin counties in 1993 (Washington State Employment Security 1994) follows:

<u>Industry</u>				
Total manufacturing	5,800	(9%)	5,400	(7.6)
Transportation and public utilities	2,300	(4%)	2,100	(3.0)
Contract construction	3,600	(6%)	4,400	(6.2)
Wholesale and retail trade	13,400	(21%)	14,600	(20.7)
Finance, insurance, and real estate	1,800	(3%)	1,900	(2.7)
Services and mining	25,500	(40%)	29,300	(41.4)
Government	11,900	(18%)	13,000	(18.4)

Nonagricultural jobs increased by 3000 during 1993 (a 4.4% growth rate). During this time period, construction employment grew by 400, trade was up by 700, finance, insurance and real estate employment grew by 100; servicing and mining was up by 1600 and government employment was up by 200 (Washington State Employment Security 1994). Employment growth for 1994 is predicted to be 3.25-3.75%, slightly lower than 1993.

4.5.2 Hanford and the Local and State Economy

In 1993, Hanford employment accounted directly for 25% of total nonagricultural employment in Benton and Franklin counties and slightly more than 0.6% of all nonagricultural statewide jobs. The total wage payroll for the Hanford Site was estimated at \$740,557,781 in 1993, which accounted for an estimated 45% of the payroll dollars earned in the area.

Previous studies have revealed that each Hanford job supports about 1.2 additional jobs in the local service sector of Benton and Franklin counties (about 2.2 total jobs) and about 1.5 additional jobs in the state's service sector (about 2.5 total jobs) (Scott et al. 1987). Similarly, each dollar of Hanford income supports about 2.1 dollars of total local incomes and about 2.4 dollars of total statewide incomes. Based on these multipliers in Benton and Franklin counties, Hanford directly or indirectly accounts for more than 40% of all jobs.

4.5.3 Demography

Information in this section is provided by two sources: 1993 Population Trends for Washington State, September 1993 (U.S. Department of Commerce 1993) and the U.S. Bureau of the Census for 1990 (U.S. Department of Commerce 1991). The Office of Financial Management provides annual estimates and information on selected population variables.

Estimates for 1993 placed population totals for Benton and Franklin Counties at 122,800 and 41,100, respectively (U.S. Department of Commerce 1993). When compared to the 1990 census data in which Benton County had 112,560 residents and Franklin County's population totaled 37,473, the current population totals reflect the continued growth occurring in these two counties (8.3% and 8.8%, respectively). This growth reflects the steady increase occurring in Eastern Washington population since 1987, with the rate of annual change climbing from 0.1% to 2.7% in 1993.

Within each county, the 1993 estimates distribute the Tri-Cities population as follows: Richland 34,080; Kennewick 45,110; and Pasco 21,370. The combined populations of Benton City, Prosser, and West Richland totaled 11,000 in 1990. The unincorporated population of Benton County was 32,610. In Franklin County, incorporated areas other than Pasco have a total population of 2,890. The unincorporated population of Franklin County was 16,840.

The 1990 estimates (no new numbers are available) of racial categories by the Bureau of the Census indicate that, in Benton and Franklin counties, Asians represent a lower proportion and individuals of Hispanic origin represent a higher proportion of the racial distribution than those in the state of Washington. Countywide, Benton and Franklin counties exhibit varying racial distributions, as indicated by the calculations in Table 4.5-2.

Benton and Franklin Counties accounted for 3% of Washington State's population (U.S. Department of Commerce 1991). Unlike previous years, Benton and Franklin Counties population demographics are quite similar to those found within the state of Washington. Fifty-six percent of the population of Benton and Franklin counties is under the age of 35, compared to 54% for the state of Washington. Within the state of Washington, 25- to 34-year-olds constitute the largest age group (17.6%) compared to 16.3% found within Benton and Franklin counties. In general, the population of Benton and Franklin counties is somewhat younger than that of Washington State. The 0- to 4-year-old age group accounts for 8.5% of the total bicounty population as compared to

Table 4.5-2. 1990 Population Estimates by Bureau of the Census Racial Categories and Hispanic Origin

	<u>Total</u>	<u>White</u>	<u>Black</u>	<u>Indian</u>	<u>Asian</u>	<u>Other Race</u>	<u>Hispanic Origin</u>
Washington State	4,866,692	4,221,622 86.7%	146,000 3.0%	76,397 1.6%	203,668 4.2%	4,435 0.1%	214,570 4.4%
Benton and Franklin Counties	150,033	123,562 82.4% ^(a)	2,305 1.5%	1,009 0.7%	3,001 2.0%	216 0.1%	19,940 13.3%
Benton County	112,560	99,778 88.6%	1,054 0.9%	792 0.7%	2,196 2.0%	116 0.1%	8,624 7.7%
Franklin County	37,473	23,784 63.5%	1,251 3.3%	217 0.6%	805 2.1%	100 0.3%	11,316 30.2%

(a) Percentage figures refer to county, not state, populations.

Source: United States Department of Commerce, Bureau of the Census, Census of Population and Housing, 1990, Summary Tape File 1A, Washington, D.C.

7.5% for Washington State. The 65-year-old and older age group constitutes 10% of the population of Benton and Franklin counties compared to 12.0% for the state of Washington.

4.5.4 Housing

In 1993, nearly 94% of all housing (of 40,344 total units) in the Tri-Cities was occupied. Single-unit housing, which represents nearly 58% of the total units, has a 97% occupancy rate throughout the Tri-Cities. Multiple-unit housing, defined as housing with two or more units, has an occupancy rate of 94%, a 3% increase since 1990. Pasco has the lowest occupancy rate, 92%, in all categories of housing; followed by Kennewick with 95%, and Richland with 96%. Representing 9% of the housing unit types, mobile homes have the lowest occupancy rate, 90%. Table 4.5-3 shows a detailed listing of total units and occupancy rate by type in the Tri-Cities.

4.5.5 Transportation

The Tri-Cities serve as a regional transportation and distribution center with major air, land, and river connections. The Tri-Cities have direct rail service, provided by Burlington Northern and Union Pacific, that connects the area to more than 35 states. The Washington Central Railroad serves eastern Washington as well. Union Pacific operates the largest fleet of refrigerated rail cars in the United States and is essential to food processors that ship frozen food from this area. Passenger rail service is provided by Amtrak, which has a station in Pasco.

Docking facilities at the Ports of Benton, Kennewick, and Pasco are important aspects of this region's infrastructure. These facilities are located on the 525-km-long commercial waterway, which comprises the Snake and Columbia rivers, that extends from the Ports of Lewiston-Clarkston in Idaho to the deep-water ports of Portland, Oregon, and Vancouver, Washington. The average shipping time from the Tri-Cities to these deep-water ports by barge is 36 hours (Evergreen Community Development Association 1986).

Daily air passenger and freight services connect the area with most major cities through the Tri-Cities Airport, located in Pasco. The airport is currently served by one national and two commuter-regional airlines. There are two runways: a main and minor crosswind. The main runway is equipped for precision instrumentation landings and takeoffs. Each runway is 7700 ft long and 150 ft wide, and can accommodate landings and takeoffs by medium-range commercial aircraft, such as the Boeing 727-200 and Douglas DC-9. The Tri-Cities airport handled about 160,844 passengers (enplanements) in 1991, an increase of approximately 6% from 1990. Projections indicate that the recently expanded terminal can serve almost 300,000 passengers annually. Two additional airports, located in Richland and Kennewick, are limited to serving private aircraft.

The Tri-Cities are linked to the region by five major highways. Route 395 joins the area with Spokane to the northeast. Both it and Route 240, which crosses through the Hanford Site, connect with Interstate 90 to the north. Route 12 links the region with Yakima to the northwest; with Lewiston, Idaho to the east; and with Walla Walla to the southeast. The

Table 4.5-3. Total units and occupancy rates (1993 estimates)^(a).

	<u>All Units</u>		<u>Single Units</u>		<u>Multiple Units</u>		<u>Mobile Homes</u>	
	<u>Total</u>	<u>Rate</u>	<u>Total</u>	<u>Rate</u>	<u>Total</u>	<u>Rate</u>	<u>Total</u>	<u>Rate</u>
Richland	14,388	96%	9,921	98%	3,827	95%	640	88%
Pasco	7,846	92%	3,679	96%	2,982	91%	1,016	86%
Kennewick	18,110	95%	9,824	97%	5,944	96%	1,942	97%
Tri-Cities average	13,448	94%	7,808	97%	4,251	94%	1,199	90%

(a) Source: U.S. Department of Commerce 1993.

area is also linked to Interstate 84 to the south, via Interstate 82, and Route 14 and Interstate 82 also connect the area to the Yakima Valley and Interstate 90 in Ellensburg. Routes 240 and 24 traverse the Hanford Site and are maintained by Washington State. Other roads within the reservation are maintained by the DOE.

4.5.6 Educational Services

Primary and Secondary. Primary and secondary education are served by the Richland, Kennewick, Pasco, and Kiona-Benton School districts. The combined 1993 spring enrollment for all districts was approximately 29,777 students, an increase of 4.6% from the 1992 total of 28,397 students. The 1993 total includes approximately 13,001 students from the Kennewick school district, about 8212 and 7094 students, respectively, in the Richland and Pasco School districts, and 1470 from Kiona-Benton. In 1993, all four school districts were operating at or near their capacity.

Post-Secondary. Post-secondary education in the Tri-Cities area is provided by a junior college, Columbia Basin College (CBC), and the Tri-Cities branch campus of Washington State University (WSU-TC). The WSU-TC offers a variety of upper-division, undergraduate, and graduate degree programs. The 1993 fall enrollment was approximately 6295 at CBC and 1117 at WSU-TC. WSU-TC is operating almost at capacity, and plans are underway for an additional building. Many of the programs offered by these two institutions are geared toward the vocational and technical needs of the area. Currently, 26 associate degree programs are available at CBC and 14 graduate programs are available at WSU-TC.

4.5.7 Health Care and Human Services

The Tri-Cities have three major hospitals and five minor emergency centers. All three hospitals offer general medical services and include a 24-hour emergency room, basic surgical services, intensive care, and neonatal care.

Kadlec Medical Center, located in Richland, has 144 beds and functions at 43.6% capacity. Their 5188 annual admissions represent more than 38% of the Tri-Cities market.

Non-Medicare/Medicaid patients accounted for 56.4%, or 2926 of their annual admissions. An average stay of 4.4 days per admission was reported for 1991.

Kennewick General Hospital maintains a 45.5% occupancy rate of its 70 beds with 4585 annual admissions. Non-Medicare/Medicaid patients in 1993 represented 52% of its total admissions. An average stay of 3.2 days per admission was reported.

Our Lady of Lourdes Hospital, located in Pasco, reported an occupancy rate of 36.5%. However, this hospital performs a significant amount of outpatient care. This outpatient income serves as a primary source of income for the hospital. In 1993, Our Lady of Lourdes had 3803 admissions of which 52% were non-Medicare/Medicaid patients. The institution reported an average admission stay of 6.05 days.

Human Services. The Tri-Cities offer a broad range of social services. State human service offices in the Tri-Cities include the Job Services office of the Employment Security Department; Food Stamp offices; the Division of Developmental Disabilities; Financial and Medical Assistance; the Child Protective Service; emergency medical service; a senior companion program; and vocational rehabilitation.

The Tri-Cities are also served by a large number of private agencies and voluntary human services organizations. The United Way, an umbrella fund-raising organization, incorporates 24 participating agencies offering more than 53 programs. These member agencies had a cumulative budget total of \$18.2 million in 1993 (United Way 1994).

4.5.8 Police and Fire Protection

Police protection in Benton and Franklin counties is provided by Benton and Franklin counties' sheriff departments, local municipal police departments, and the Washington State Patrol Division headquartered in Kennewick. Table 4.5-4 shows the number of commissioned officers and patrol cars in each department in December 1993. The Kennewick, Richland, and Pasco municipal departments maintain the largest staffs of commissioned officers with 58, 44, and 39, respectively.

Table 4.5-4. Police personnel in the Tri-Cities, 1992.

	<u>Commissioned Officers</u>	<u>Patrol Cars</u>
Kennewick Municipal	58	32
Pasco Municipal	39	11
Richland Municipal	44	14
West Richland Municipal	7	9
County Sheriff, Benton County	43	50
County Sheriff, Franklin County	23	23

Source: Personal communication with each department office, January 1994.

In Benton County, violent crimes occurred in 1992 at a rate of 3.1/year per 1000 residents, and property crimes occurred at 46.6/year per 1000 residents, a decrease of 5%. Table 4.5-5 illustrates that both violent and property crimes occurred at a lesser rate in Richland than in Kennewick. Pasco violent crime and property crime rates were the highest of the Tri-Cities at 11.2 per 1000 residents and 92.4 per 1000 residents, respectively.

Benton County's violent crime rate per 1000 residents (3.1) was less than that of Washington State (5.4), and Franklin County's rate (7.6) exceeded the Washington State rates.

Table 4.5-6 indicates the number of fire-fighting personnel, both paid and unpaid, on the staffs of fire districts in the area.

Hanford Fire Station. The Hanford Fire patrol, composed of 126 firefighters, is trained to dispose of hazardous waste and to fight chemical fires. During the 24-hour duty period, 5 firefighters cover the 1100 Area, 7 protect the 300 Area, 7 watch the 200-East and 200-West Areas, 6 are responsible for the 100 Area, and 6 cover the 400 Area, which includes the WPPSS area. To perform their responsibilities, each station has access to a Hazardous Material Response Vehicle that is equipped with chemical fire-extinguishing equipment, an attack truck that carries foam, halon, and Purple-K dry chemical, a mobile air truck that provides air for gasmasks, and a transport tanker that supplies water to six brush trucks. They have five ambulances and contact with local hospitals.

4.5.9 Parks and Recreation

The convergence of the Columbia, Snake, and Yakima rivers offers the residents of the Tri-Cities a variety of recreational opportunities.

Table 4.5-5. Violent and property crimes in the Tri-Cities.

	<u>Violent Crimes per 1000 Residents</u>	<u>Property Crimes per 1000 Residents</u>
Benton County	3.1	46.6
Richland	2.0	37.5
Kennewick	3.4	72.5
Franklin County	7.6	61.6
Pasco	11.2	92.4
Yakima County	6.8	74.8
Washington State	5.4	57.2

Source: Personal Communication. Uniform Crime Reporting Program, Washington Association of Sheriffs and Police Chiefs.

Table 4.5-6. Fire protection in the Tri-Cities, 1993.

	<u>Fire Fighting Personnel</u>	<u>Volunteers</u>	<u>Total</u>	<u>Service Area</u>
Kennewick	54	0	54	City of Kennewick
Pasco	30	0	30	City of Pasco
Richland	50	0	50	City of Richland
BCRFD 1	6	120	126	Kennewick Area
BCRFD 2	1	31	32	Benton City
BCRFD 4	4	30	34	West Richland

Source: Personal communication with each department office, January 1994.

The Lower Snake River Project includes Ice Harbor Lower Monumental, Little Goose, Lower Granite locks and dams, and a levee system and parkway at Clarkston and Lewiston. While navigation capabilities and the electrical output represent the major benefits of this project, recreational benefits have also resulted. The Lower Snake River Project provides boating, camping, and picnicking facilities in nearly a dozen different areas along the Snake River. In 1993, over 2.5 million people visited the area and participated in activities along the river.

Similarly, the Columbia River provides ample water recreational opportunities on the lakes formed by the dams. Lake Wallula, formed by McNary Dam, offers a large variety of parks and activities, which attracted more than 3 million visitors in 1993. The Columbia River Basin is also a popular area for migratory waterfowl and upland game bird hunting.

Other opportunities for recreational activities in the Tri-Cities are accommodated by the indoor and outdoor facilities available, some of which are listed in Table 4.5-7. Numerous tennis courts, ball fields, and golf courses offer outdoor recreation to residents and tourists. Several privately owned health clubs in the area offer indoor tennis and racquetball courts, pools, and exercise programs. Bowling lanes and roller skating rinks also serve each of the Tri-Cities.

4.5.10 Utilities

Water. The principal source of water in the Tri-Cities and the Hanford Site is the Columbia River from which the water systems of Richland, Pasco, and Kennewick draw a large portion of the average 11.78 billion gallons used in 1993. Each city operates its own supply and treatment system. The Richland water supply system derives about 67% of its water from the Columbia River, approximately 15-20% from a well field in North Richland, and the remaining from groundwater wells. The city of Richland's total usage in 1993 was 6.35 billion gallons. This current usage represents approximately 58% of the maximum supply capacity. The city of Pasco system likewise draws from the Columbia River for its

Table 4.5-7. Examples of physical recreational facilities available in the Tri-Cities.

	<u>Facilities</u>
Tennis	62 outdoor courts (e.g., Sylvester Park, Howard Amon Park, Pasco High School). Indoor courts at Tri-City Court Club and Columbia Basin Racquet Club.
Golf	Seven courses including Tri-City Country Club, Canyon Lakes, and West Richland Municipal Golf Course. Several driving ranges and pro shops are also available.
Bowling	Lanes in each city including Atomic Bowling Center, Celebrity Bowl, Columbia Lanes, Go-Bowl and Town & Country Lanes.
Swimming	Private (e.g., Ranchette Estates, Oasis Water Park) and public (e.g., Richland, Pasco, Kennewick) swimming pools in the area. Boating, water-skiing, and swimming on the Columbia River in the Tri-Cities area.
Ball	Baseball fields and basketball courts are located throughout the Tri-Cities including Badger Canyon, Craighill Playgrounds, Stevens Playground, and Lewis and Clark School. Soccer and football fields are also located in various areas.
Skating	Rollerskating, iceskating, and skateboard facilities.
Camping	Several hundred campsites within driving distance from the Tri-Cities area including Levy Park, Fishhook Park, and Sun Lakes.
Fishing	Steelhead, sturgeon, trout, walleye, bass, and crappie fishing in the lakes and rivers near the Tri-Cities area.
Hunting	Duck, geese, pheasant, and quail hunting. Deer and elk hunting in the Blue Mountains and the Cascade Range.

water needs. The 1993 estimate of consumption is 1.98 billion gallons. The Kennewick system uses two wells and the Columbia River for its supply. These wells serve as the sole source of water between November and March and can provide approximately 62% of the total maximum supply of 7.3 billion gallons. Total usage in 1993 was 3.44 billion gallons.

The major incorporated areas of Benton and Franklin counties are served by municipal wastewater treatment systems, whereas the unincorporated areas are served by onsite septic systems. Richland's wastewater treatment system is designed to treat a total capacity of 27 million m³/yr (a daily average flow of 8.9 million gallons/day (mgd) with a peak flow of 44 mgd). In 1991, the system processed an average 4.83 mgd. The Kennewick system similarly has significant excess capacity; with a treatment capability of 12 million m³/yr (or 8.7 mgd), 1991 usage was 4.8 mgd. Pasco's waste-treatment system processes an average of 2.22 mgd, while the system could treat 4.25 mgd or 34.6 million m³.

Electricity. In the Tri-Cities, electricity is provided by the Benton County Public Utility District, Benton Rural Electrical Association, Franklin County Public Utility District, and City of Richland Energy Services Department. All the power that these utilities provide in the local area is purchased from the Bonneville Power Administration (BPA), a federal power marketing agency. The average rate for residential customers served by the three local utilities is approximately \$0.054/kWh. Electrical power for the Hanford Site is purchased wholesale from BPA. Energy requirements for the Site during FY 1988 exceeded 550 average MW.

Natural gas, provided by the Cascade Natural Gas Corporation, serves a small portion of residents, with 5800 residential customers in December 1993.

In the Pacific Northwest, hydropower, and to a lesser extent, coal and nuclear power, constitute the region's electrical generation system. Total nameplate generating capacity is about 40,270 MW. Approximately 74% of the region's installed generating capacity is hydroelectric, which supplies approximately 65% of the electricity used by the region. Coal-fired generating capacity is 6702 MW in the region, or 16% of the region's electrical generating capacity. Two commercial nuclear power plants are in service in the Pacific Northwest, with a 2247-MW capacity of 6% of the region's generating capacity. Oil and natural gas account for about 3% of capacity.

The region's electrical power system, more than any other system in the nation, is dominated by hydropower. On average, the region's hydropower system can produce 16,400 MW. Variable precipitation and limited storage capabilities alter the system's output from 12,300 average MW under critical water conditions to 20,000 average MW in record high-water years. The Pacific Northwest system's reliance on hydroelectric power means that it is more constrained by the seasonal variations in peak demand than in meeting momentary peak demand.

Throughout the 1980s, the Northwest had more electric power than it required and was operating with a surplus. This surplus has been exhausted, however, and there is only approximately enough power supplied by the existing system to meet the current electricity needs. Hydropower improvement projects currently under construction in the Northwest include about 150 MW of new capacity. The cost and availability of several other resources are currently being studied (Northwest Power Planning Council 1986).

4.5.11 Land Use

The Hanford Site encompasses 1450 km² (560 mi²) and includes several DOE operational areas. The major areas are as follows:

- The entire Hanford Site has been designated a National Environmental Research Park (NERP).
- The 100 Areas, bordering on the right bank (south shore) of the Columbia River, are the sites of the eight retired plutonium production reactors and the N Reactor. The

facilities in the 100 Area are being placed in a stabilized state for ultimate decommissioning. The N Reactor Deactivation Program covers the period from FY 1992 through FY 1997. The 100 Areas occupy about 11 km² (4 mi²).

- The 200-West and 200-East Areas are located on a plateau about 8 and 11 km, respectively, from the Columbia River. These areas have been dedicated for some time to fuel reprocessing and waste processing management and disposal activities. The 200 Areas cover about 16 km² (6 mi²).
- The 300 Area, located just north of the City of Richland, is the site of nuclear research and development. This area covers 1.5 km² (.6 mi²).
- The 400 Area is about 8 km (5 mi) north of the 300 Area and is the site of the Fast Flux Test Facility used in the testing of breeder reactor systems. In December 1993, the Secretary of Energy ordered the Fast Flux Test Facility to be shutdown, and the process has begun. The goal is to reach a radiologically and industrially safe shutdown in approximately 5 years. Also included in this area is the Fuels and Material Examination Facility.
- The 600 Area includes all of the Hanford Site not occupied by the 100, 200, 300, or 400 Areas. Land uses within the 600 Area include:
 1. 310 km² (120 mi²), known as the Fitzner-Eberhardt Arid Land Ecology Reserve (ALE), which has been set aside for ecological studies.
 2. 4 km² (1.5 mi²) leased by Washington State, a part of which is used for commercial low-level radioactive waste disposal.
 3. 4.4 km² (1.6 mi²) for Washington Public Power Supply System nuclear power plants.
 4. 2.6 km² (1 mi²) transferred to Washington State as a potential site for the disposal of nonradioactive hazardous wastes.
 5. About 130 km² (50 mi²) under revocable use permit to the U.S. Fish and Wildlife Service for a wildlife refuge.
 6. 225 km² (87 mi²) under revocable use permit to the Washington State Department of Fish and Wildlife for recreational game management.
 7. Support facilities for the controlled access areas.

An area of 665 km² (257 mi²) has been designated for ALE, the U.S. Fish and Wildlife Service, wildlife refuges, and the Washington State Department of Game management area (DOE 1986).

Land use in other areas includes urban and industrial development, irrigated and dry-land farming, and grazing. In 1985, wheat represented the largest single crop in terms of area planted in Benton and Franklin counties with 116,000 hectares. Corn, alfalfa, hay, barley, and grapes are other major crops in Benton and Franklin counties.

In 1986, the Columbia Basin Project, a major irrigation project to the north of the Tri-Cities, produced gross crop returns of \$343 million, representing 19% of all crops grown in Washington State. In 1986, the average gross crop value per irrigated acre was \$664.00. The largest percentage of irrigated acres produced alfalfa hay (29.4% of irrigated acres), wheat (15.0%), and feed-grain corn (9.4%). Other significant crops are potatoes, apples, dry beans, asparagus, and pea seed.

4.5.12 Offsite Historical and Cultural Sites

Currently, 16 archaeological properties are located near the Hanford Site. These properties are listed in the National Register of Historic Places.

4.5.13 Visual Resources

The land in the vicinity of the Hanford Site is generally flat with little relief. Rattlesnake Mountain, rising to 1060 m (3477 ft) above mean sea level, forms the western boundary of the site, and Gable Mountain and Gable Butte are the highest land forms within the site. Both the Columbia River, flowing across the northern part of the site and forming the eastern boundary, and the spring-blooming desert flowers provide a visual source of enjoyment to people. White Bluffs, the steep bluffs above the northern boundary of the river in this region, are a striking feature of the landscape.

4.6 Noise

Noise is technically defined as sound waves perceptible to the human ear. Sound waves are characterized by frequency, measured in Hertz (Hz), and sound pressure expressed as decibels (dB). Humans have a perceptible hearing range of 31 to 20,000 Hz. The decibel is a value equal to 10 times the logarithm of the ratio of a sound pressure squared to a standard reference sound-pressure level (20 micropascals) squared. The threshold of audibility ranges from about 60 dB at a frequency of 31 Hz to less than about 1dB between 900 and 8000 Hz. [For regulatory purposes, noise levels for perceptible frequencies are weighted to provide an A-weighted sound level (dBA) that correlates highly with individual community response to noise]. Sound pressure levels outside the range of human hearing are not considered noise in a regulatory sense, even though wildlife may be able to hear at these frequencies.

Noise levels are often reported as the equivalent sound level (Leq). The Leq is expressed in A-weighted (dBA) over a specified period of time, usually 1 or 24 hours. The Leq is the equivalent steady sound level that, if continuous during a specified time period, would contain the same total energy as the actual time-varying sound over the monitored or modelled time period.

4.6.1 Background Information

Studies of the propagation of noise at Hanford have been concerned primarily with occupational noise at work sites. Environmental noise levels have not been extensively evaluated because of the remoteness of most Hanford activities and isolation from receptors that are covered by federal or state statutes. This discussion focuses on what few environmental noise data are available. The majority of available information consists of model predictions, which in many cases have not been verified because the predictions indicated that the potential to violate state or federal standards is remote or unrealistic.

4.6.2 Environmental Noise Regulations

The Noise Control Act of 1972 and its subsequent amendments (Quiet Communities Act of 1978 and 40 CFR 201-211) direct the regulation of environmental noise to the state. The State of Washington has adopted RCW 70.107, which authorizes the Department of Ecology to implement rules consistent with federal noise control legislation. RCW 70.107 and the implementing regulations embodied in WAC 173-60 through 173-70 defined the regulation of environmental noise levels. Maximum noise levels are defined for the zoning of the area in accord with environmental designation for noise abatement (EDNA). The Hanford Site is classified as a Class C EDNA on the basis of industrial activities. Unoccupied areas are also classified as Class C areas by default because they are neither Class A (residential) or Class B (commercial). Maximum noise levels are established based on the EDNA classification of the receiving area and the source area (Table 4.6-1).

4.6.3 Hanford Site Sound Levels

Most industrial facilities on the Hanford Site are located far enough away from the site boundary that noise levels at the boundary are not measurable or are barely distinguishable

Table 4.6-1. Applicable state noise limitations for the Hanford Site based on source and receptor EDNA designation (values are dBA).

Source <u>Hanford Site</u>	<u>Receptor</u>		
	<u>Class A Residential</u>	<u>Class B Commercial</u>	<u>Class C Industrial</u>
Class C - Day	60	65	70
Night	50	--	--

from background noise levels. Modeling of environmental noises has been performed for commercial reactors and State Highway 240 through the Hanford Site. These data are not concerned with background levels of noise and are not reviewed here. There are two sources of measured environmental noise at Hanford. Environmental noise measurements were made in 1981 during site characterization of the Skagit/Hanford Nuclear Power Plant Site (NRC 1982). The Hanford Site was considered as the site for a geologic waste repository (Basalt Waste Isolation Project, BWIP) for spent commercial nuclear fuel and other high-level nuclear waste. Site characterization studies performed in 1987 included measurement of background environmental noise levels at five sites on the Hanford Site. Additionally, certain activities such as well drilling and sampling have the potential for producing noise in the field apart from major permanent facilities.

Recently, the potential impact of traffic noise resulting from Hanford Site activities has been prepared for a draft EIS addressing the siting of the proposed New Production Reactors NPR (DOE 1991). While this EIS does not include any new baseline measurements, it does address the traffic component of noise and provides modeled "baseline" measurements of traffic noise for the Hanford Site and adjacent communities.

Skagit/Hanford Data

Preconstruction measurements of environmental noise were taken in June 1981 on the Hanford Site (NRC 1982). Fifteen sites were monitored and noise levels ranged from 30 to 60.5 dBA (Leq). The values for isolated areas ranged from 30 to 38.8 dBA. Measurements taken around the sites where the Supply System was constructing nuclear power plants (WNP-1, WNP-2, and WNP-4) ranged from 50.6 to 64 dBA. Measurements taken along the Columbia River near the intake structures for WNP-2 were 47.7 and 52.1 dBA compared with more remote river noise levels of 45.9 dBA (measured about 3 miles upstream of the intake structures). Community noise levels in North Richland (3000 Area at Horn Rapids Road and the By-Pass Highway) were 60.5 BA.

BWIP Data

Background noise levels were determined at five sites located within the Hanford Site. Noise levels are expressed as equivalent sound levels for 24 hours (Leq-24). Sample location date, and Leq-24 are listed in Table 4.6-2. Wind was identified as the primary contributor to background noise levels with winds exceeding 19 km/h (12 mi/h) significantly affecting noise levels. Coleman concludes that background noise levels in undeveloped areas at Hanford can best be described as a mean Leq-24 of 24-36 DBA. Periods of high wind, which normally occur in the spring, would elevate background noise levels.

NPR EIS

Baseline noise estimates were determined for two locations: State Route (SR) 24, leading from the Hanford Site west to Yakima, and SR 240, south of the Site and west of Richland where it handles maximum traffic volume (DOE 1991). Traffic volumes were predicted based on an operational work force and a construction work force. Both peak

Table 4.6-2. Background noise levels measured at isolated areas.

<u>Site</u>	<u>Location</u>			<u>Date</u>	<u>Leq-24 (dBA)</u>
	<u>Section</u>	<u>Range</u>	<u>Township</u>		
1	9	R25E	T12N	07-10-87	41.7
				07-11-87	40.7
				07-12-87	36.0
				07-13-87	37.2
				07-14-87	35.6
2	26	R25E	T13N	07-25-87	43.9
				07-26-87	38.8
				07-27-87	43.8
				07-28-87	37.7
				07-29-87	43.2
3	18	R26E	T12N	08-08-87	39.0
				08-09-87	35.4
				08-10-87	51.4 ^(a)
				08-11-87	56.7 ^(a)
				08-12-87	36.0
4	34	R27E	T11N	09-09-87	35.2
				09-10-87	34.8
				09-11-87	36.0
				09-12-87	33.2
				09-13-87	37.3
5	14	R28E	T11N	10-15-87	40.8
				10-16-87	36.8
				10-17-87	33.7
				10-18-87	31.3
				10-19-87	35.9

(a) Leq includes grader noise.

(rush hour) and off-peak hours were modeled. Noise levels were expressed in Leq for 1 hr periods in dBA at a receptor located 15 miles from the road edge (Table 4.6-3). Adverse community responses would not be expected at increases of 5 dBA over background noise levels.

Noise Levels of Hanford Field Activities

In the interest of protecting Hanford workers and complying with (OSHA) standards for noise in the workplace, the Hanford Environmental Health Foundation has monitored noise

Table 4.6-3. Modeled noise resulting from automobile traffic at Hanford in association with New Production Reactor EIS (DOE 1991)^(a).

<u>Location</u> ^(b)	<u>Scenario</u>	<u>Traffic flow (Vehicles/hr)</u>		<u>Noise levels (Leq-1 hr in DBA)</u>		<u>Maximum Increase (dBA)</u>
		<u>Baseline</u>	<u>Maximum</u> ^(c)	<u>Baseline noise levels</u>	<u>Modeled noise levels</u> ^(c)	
Construction Phase						
SR24	Off-Peak	91	91	62.0	62.0	0.0
	Peak	91	343	62.0		
SR240	Off-Peak	571	579	70.2	70.6	0.4
	Peak	571	2839	70.2	73.5	3.3
Operation Phase						
SR24	Off-Peak	91	91	62.0	62.0	0.0
	Peak	300	386	65.7	66.2	1.5
SR240	Off-Peak	571	582	70.2	70.5	0.3
	Peak	2239	3009	74.1	74.7	0.6

(a) Measured 15 m from the road edge.

(b) SR24 leads to Yakima; SR 240 leads to the Tri-City Metropolitan Area.

(c) Traffic flow and noise estimates varied with NPR technology; the maximum impact from three NPR techniques are shown here.

levels resulting from several routine operations performed at Hanford. Occupational sources of noise propagated in the field have been summarized in Table 4.6-4. These levels are reported here because operations such as well sampling are conducted in the field away from established industrial areas and have the potential for disturbing sensitive wildlife.

Table 4.6-4. Monitored Levels of Noise Propagated from Outdoor Activities at the Hanford Site^(a).

Activity	Average Noise Level	Maximum Noise Level	Year Measured
Water wagon operation	104.5	111.9	1984
Well sampling	74.8 - 78.2		1987
Truck	78 - 83		1989
Compressor	88 - 90		
Generator	93 - 95		
Well drilling, Well 32-2	98 - 102	102	1987
Well drilling, Well 32-3	105 - 11	120 - 125	1987
Well drilling, Well 33-29	89 - 91		1987
Pile driver (diesel, 1.5 m [5 ft] from source)	118 - 119		
Tank farm filter building (9 m [30 ft] from source)	86		1976

(a) Noise levels measured in decibels (dB).

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5.0 Models Used to Estimate Environmental Impacts

Potential and/or realized environmental impacts from nuclear materials at the Hanford Site are evaluated using a wide assortment of computer programs. Most of these programs operate on one or more computer systems from supercomputers to PCs. Most of the programs are well documented and include source-code listings and special instructions for computer users. The use of a modular programming format and restricted use of machine-dependent code also appear to be characteristic of most programs. These features allow for easier modification (or upgrading) of the codes and generally increase program transportability.

A summary of the computer programs described in this chapter is provided in Table 5.1. The programs contain mathematical models that estimate radiation dose or groundwater transport, or health risk of both radionuclides and chemicals.

Radiation dose models are used to calculate dose to selected targets (e.g., organs, individuals, or populations) from all major environmental pathways (i.e., air, soil, water, and food chain). Calculations may be performed for both acute (one-time) and chronic (single years, human lifetimes, or thousands of years) exposures. Three types of radiation doses are generally reported:

- **1-year dose:** the population or individual dose resulting from 1 year of external plus internal exposure
- **committed dose:** the population or individual dose resulting from 1 year of external and internal exposure plus the continued internal dose accumulated from that year's combined inhalation and ingestion exposure
- **accumulated dose:** the population or individual dose (external plus internal) accumulated over a lifetime (usually 50 or 70 years).

The groundwater programs described in this chapter actually include a rather wide assortment of hydrologic and hydrogeochemical models. They are used primarily to simulate subsurface flow (saturated and/or unsaturated) and heat and solute transport through geologic media i.e., soils, fractured rock). Most have been designed to accommodate the unique geologic and climatic features (i.e., flood basalts and arid conditions) that characterize the Hanford Site. They range in sophistication (i.e., size, speed, and cost of operation, graphics capabilities, etc.) from relatively simple one-dimensional models, to more complex two- and three-dimensional models.

Listings for each of the programs appearing in this chapter include 1) a general description with a summary of the key features and primary application of each program, 2) a list of important assumptions and/or limitations that apply to each program, 3) special programming considerations, including the software and hardware compatibility of the current version of the program and, if applicable, a list of supplemental documentation,

Table 5.1. Summary of supported computer programs

Program	Category	Description or Primary Use
CAP-88	Radiation Dose	Calculates maximum individual and population dose for chronic air releases of radionuclides
CFEST	Groundwater Transport	Coupled fluid, energy, and solute transport in confined aquifers
GENII	Radiation Dose	Calculates doses from air and water releases of radionuclides via various pathways
MAGNAS3	Groundwater Transport	Three-dimensional model for groundwater flow through porous media
MEPAS	Health Risk	Calculates health risks from radionuclides and chemicals via air and water pathways
MSTS	Groundwater Transport	Three-dimensional thermal and hydraulic transport through variably saturated subsurface environments
ORIGEN2	Radionuclide Inventory	Radionuclide generation and decay
PORFLO-3	Groundwater Transport	Continuum three-dimensional model for fluid flow, heat transfer, and mass transport in porous media
PORFLOW	Groundwater Transport	Multiphase groundwater flow model
RADTRAN 4	Radiation Dose	Health and economic impacts associated with transportation of radioactive materials
RESRAD	Radiation Dose	Calculates site-specific residual radiation contamination guidelines
STOMP	Groundwater Transport	Engineering simulation for evaluating subsurface remediation technologies
TRANSS	Groundwater Transport	One-dimensional groundwater transport model
UNSAT-H	Groundwater Transport	Unsaturated flow model
VAM3DCG	Groundwater Transport	Three-dimensional simulation of moisture movement and solute transport in variably saturated porous media

such as user's guides, 4) a current contact with a name and address of an individual (or agency) who can provide updated information on a particular program, and 5) a listing of all relevant source documentation for each program. A current contact may not be listed

for programs that are not in current usage or in cases in which the principal program author(s) cannot be contacted or is no longer involved with the program. Programs falling into this category have been listed in Appendix A.

In most cases this information has been taken directly from the abstracts, summaries, or introductory sections of the original program documentation. Because many programs undergo frequent revision, material documenting their mathematical models and/or computer implementation is often out of date a short time after it is released. In addition, IBM PC versions of some programs previously only designed to run on mainframes are now available. Therefore, readers are urged to check with the current contacts if in doubt about the capabilities of a particular program.

Finally, the measurement of uncertainty in the evaluation of model performance deserves special mention. Models use mathematical analogues to describe complex physical and/or chemical processes and, for this reason, often provide a greatly simplified view of the "real world." The ability of a model to provide an accurate simulation of a particular process is dependent on many factors. For instance, errors can result from 1) invalid assumptions concerning key model parameters (i.e., boundary conditions, dispersion characteristics, etc.), 2) the use of inappropriate or overly simplistic analogues, 3) calculational errors in the computer codes, and 4) basic inadequacies in the input data. In some cases program performance may be significantly improved by more rigorous sampling, but additional data collection or analysis is often impractical because of time and cost constraints. Serious errors can also arise from model misuse or misinterpretation of program output. Computer programs are designed for specific applications, and users must be aware of their limitations. Consultation with the program author(s) or an experienced user should serve to avoid most problems of this nature.

There are several standard procedures for testing the veracity of mathematical models and the computer programs that use them. Model verification involves comparing program output with results generated by hand calculations. Most models are thoroughly verified during the normal course of program development. Program output may also be compared with results from a related, and usually previously verified, model. This is referred to as benchmarking. The most rigorous test of model uncertainty includes some form of field validation. This involves testing model predictions against actual field data or data obtained from laboratory experiments, which simulate conditions similar to those the program was designed to evaluate. Field validation is not an absolute test of model accuracy, however, and great care should be taken in interpreting the results from these kinds of studies. For the most part, validation studies only provide a limited assessment of model performance (i.e., results may only apply to the conditions defined for the test case). Models used to predict long-term trends (e.g., 10,000-year dose) or impacts resulting from postulated accidents generally cannot be validated. Nevertheless, validation studies provide an additional level of confidence that is highly desirable for engineers, scientists, and management personnel who must make decisions regarding the selection and operation of computer programs used in environmental assessment.

An attempt has been made to acknowledge any verification or validation studies that are cited in the original documentation for each of the programs described in this chapter. Regrettably, unpublished work and/or studies appearing in subsequent or supplemental documents may have been overlooked.

Hanford-specific parameter values for use in these programs may be found in the document put out by the Hanford Environmental Dose Overview Panel (Schreckhise et al. 1993). This document is periodically updated to reflect the latest changes in environmental parameter values. In addition the document gives advice on how to implement the programs for various Hanford environmental and health dose estimates.

5.1 CAP-88

CAP-88 is a software package that is currently specified by EPA to implement the atmospheric transport and dose assessment required to demonstrate compliance with the National Emission Standards for Hazardous Air Pollutants (NESHAPs) for radionuclides established by 1990 amendments to the clean air act. CAP-88 stands for Clean Air Assessment Package - 1988, which is an update of the previous EPA AIRDOS and DARTAB codes. The package consists of programs to perform atmospheric dispersion, radiation dosimetry, and risk calculations for chronic radionuclide releases to the atmosphere.

Three versions of the software are currently approved by EPA for demonstrating compliance with the clean air act NESHAPs at DOE facilities -- CAP-88, AIRDOS-PC and CAP88-PC. The initial version of the CAP-88 software runs on minicomputer systems (IBM or DEC VAX). The programs supplied with the code package include AIRDOS2, which performs the atmospheric dispersion and deposition calculations and DARTAB2, which performs the dosimetry and risk calculations. The dose and risk factor library supplied with the package consists of output from the RADRISK code. The package also includes several utility programs: PREPAR - a preprocessor that assists the user by converting a FORTRAN namelist input file to the format used by AIRDOS2 (Sjoreen and Miller 1984), PREDA - a preprocessor to create DARTAB2 input data sets from AIRDOS2 output, and RADFMT - a utility to convert RADRISK.BCD (a data file of dose and risk factors for use by DARTAB) to binary format. The AIRDOS-PC and CAP88-PC versions of the software are somewhat simplified versions of the mainframe CAP-88 package that operate on IBM or compatible personal computers using a menu-driven interface.

The CAP-88 software is used to estimate radionuclide concentrations in air; rates of deposition on ground surfaces; ground surface concentrations; and intake rates via inhalation of air and ingestion of vegetables, milk, and meat from airborne releases of up to 36 radionuclides. A modified Gaussian plume equation is used to estimate both horizontal and vertical dispersion of up to 36 radionuclides released from one to six stacks or area sources. Exposure pathways considered by the code include air submersion, inhalation, ground irradiation, immersion in water (deposition into swimming pools), and ingestion of

food products produced in the region. Radiation dose to populations and individuals are estimated as the effective dose equivalent using calculated concentrations in environmental media.

The code is distributed with a set of radionuclide-specific data that generally corresponds to the ICRP Publication 30 internal dosimetry models (ICRP 1979-1982) for calculating a 50-year effective dose equivalent. The risk of health effects, including genetic effects and fatal cancers, can also be estimated by organ and radionuclide. Dose and risk factors are generated by the RADRISK code, and are supplied as a text or binary data file with the CAP-88 package.

Assumptions and/or Limitations

- Straight-line Gaussian plume dispersion model used with Pasquill dispersion coefficients calculated using Briggs' equations (Gifford 1976)
- Plume rise (either momentum or buoyancy terms) are calculated by the code, or a pre-calculated value for plume rise may be supplied directly by the user
- Plume depletion is calculated for both wet and dry deposition
- Gravitational settling included
- Both point and area sources are supported
- Radionuclide concentrations in fresh vegetables, milk, and meat are estimated using the food chain models in NRC Regulatory Guide 1.109
- Each calculation is limited to 36 nuclides, 20 downwind distances, and 16 directions.
- Atmospheric dispersion and environmental uptake models are appropriate for low-level chronic releases; they are not applicable to short-term or accidental releases of radionuclides.

Programming Considerations

The program is written in FORTRAN IV using the IBM 3081 or 3033 running under the OS/VMS operating system and FORTRAN 77 for the DEC VAX running under VMS. At present an IBM PC version, CAP88-PC, is available from EPA (Parks 1992). The code packages are also distributed by the Oak Ridge Radiation Shielding Information Center (RSIC) as CCC/542A (IBM Mainframe version), CCC/542B (DEC VAX version), CCC/542C (CAP88-PC for IBM and compatible personal computers) and CCC/551 (AIRDOS-PC for IBM and compatible personal computers).

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5.2 CFEST

CFEST provides a multidimensional analysis of coupled fluid, energy, and solute transport and has been used to model nonisothermal events in confined aquifer systems. The latest supercomputer version, CFEST-SC, was developed from an earlier version of the CFEST code (Gupta et al. 1987) and is suitable for operation on a CRAY X-MP^(a) computer with a UNICOS operating system. This newest version of the code can be installed and run on most unix boxes, e.g., it is currently installed and operating on Silicon

(a) CRAY, CRAY X-MP, and UNICOS are trademarks of CRAY Research Incorporated, Mendota Heights, Minnesota.

Graphics^(a), Sun Microsystems^(b), and IBM^(c) System 6000 workstations. CFEST Version SC-01 was developed by Battelle Memorial Institute, Pacific Northwest Laboratories, Copyright © 1988 by Battelle Memorial Institute "All rights reserved." The previous DEC^(d) VAX-11/780 virtual memory version of the code was developed under the Department of Energy's (DOE) Civilian Radioactive Waste Management Program (Gupta et al. 1987) by Battelle Project Management Division, Office of nuclear Waste Isolation and Pacific Northwest Laboratory (PNL). The earlier DEC PDP 11/70 version of the CFEST code was developed for the Underground Energy Storage Program managed for the DOE by Pacific Northwest Laboratory (Gupta et al. 1982) and was executed on small computers with a maximum core storage of 16K-32 bit words. CFEST-SC and its predecessors are an extension of the Finite Element Three-Dimensional Ground-Water (FE3DGW) code (Gupta et al. 1979; 1984). Both the FE3DGW code and the various versions of the CFEST code are highly interactive and employ a staged execution structure.

CFEST-SC is a finite element code for two- or three-dimensional analysis of hydrologic flow, heat transport, and single-constituent solute transport in subsurface confined environments at either the regional or local scale. Only single-phase Darcian flow is considered in this multidimensional analysis package, but either constant or variable density systems can be modeled. While the code is formulated for confined aquifer systems, water table environments can be modeled by an updating of the structure of the surface elements in conjunction with an iterative use of the various subprograms of the CFEST-SC code. In the Cartesian coordinate system the code can simulate flow in a horizontal plane, in a vertical plane, or in a fully three-dimensional region. An option also exists for the axisymmetric analysis of a vertical cross section. The code employs bilinear quadrilateral elements in all two-dimensional analyses and trilinear quadrilateral solid elements in three-dimensional simulations. Both steady-state and transient simulations are possible.

The CFEST-SC code can be used to contribute to a wide variety of projects involving saturated aquifer settings including; 1) regional and local hydrologic characterization, 2) simulation of uncoupled heat transport and contaminant transport with retardation (a linear sorption isotherm) and decay, 3) simulation of coupled heat and contaminant or salinity transport (i.e., density dependent flows), 4) flow path and travel time analyses, and 5) analyses and interpretation of aquifer and tracer field tests. The CFEST-SC code has been applied to several studies involving water flow and contaminant transport in the unconfined and confined aquifers underlying the Hanford Site. These studies have dealt with inverse calibration of the unconfined aquifer model (Jacobson and Freshley 1990), the migration of lead through soils and groundwater (Rhoads et al. 1992), and linking CFEST with a geographic information system (Wurstner and Devary 1993). In an unpublished

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(b) Sun Microsystems is a trademark of Sun Microsystems, Inc., Mountain View, California.

(c) IBM is a trademark of International Business Machines Corporation, Austin, Texas.

(d) DEC, VAX, PDP, and VMS are trademarks of Digital Equipment Corporation, Maynard, Massachusetts.

work Brockhaus (1989) completed a masters thesis at the University of Washington, Seattle, involving a fully three-dimensional CFEST model of the groundwater aquifer system underlying Hanford.

Assumptions and/or Limitations

The CFEST code solves the coupled partial differential equations for pressure, temperature, and solute concentration in a geologic formation. These equations are coupled through the fluid properties of density and viscosity. Porosity is treated as a function of pressure only, i.e., it is not affected by either chemical or energy states. The user has the option to solve one or all of the dependent variables. The following assumptions are incorporated into the equations encoded and the parameters required to execute the CFEST code:

- The flow is transient and laminar (Darcian).
- The permeability and coordinate axes are collinear. The rotation of elements to anisotropy axes is not performed. Finite-element formulations, in general, permit such a rotation. In aquifer problems, horizontal dimensions are far greater than vertical. Therefore, variation between anisotropy axes and the coordinate axes is not significant for regional models. Moreover, field data are generally also limited with respect to anisotropic properties.
- Fluid density is a function of pressure, temperature, and solute concentration.
- Fluid viscosity is a function of temperature and concentration.
- The injected fluid is miscible with the resident aquifer fluids.
- Aquifer properties (i.e., porosity, permeability, and thickness) vary spatially. The thickness variations are nodal while material properties are element constant.
- Hydrodynamic dispersion is a function of fluid velocity.
- Boundary conditions permit natural water movement in the aquifer; heat losses or gains to adjacent formations; and the location of injection, production, and observation wells anywhere within the system.
- The porous medium and fluid are compressible.
- The fluid and porous media are in thermal equilibrium.
- Rock density and heat capacity remain constant.
- Viscous dissipation is negligible with respect to the energy balance.

Verification. CFEST has been the subject of extensive verification efforts (see Chapters 4 in Cole et al. 1988; Gupta et al. 1987, and Gupta et al. 1982). Solutions have been obtained to 10 problems within three broad categories: 1) flow prediction tests (steady and unsteady drawdown in a confined aquifer, unsteady drawdown in a leaky confined aquifer, uniform regional flow with sources and sinks), 2) energy and solute mass transport verifications (Dirichlet upstream boundary condition, mixed upstream boundary condition, approximate analytical solution to an axisymmetric analysis including radially varying velocity), and 3) energy transport including cap and bedrock conduction (Avdonin's radial problem, Avdonin's linear problem, Gringarten-Sauty problem). Other verification and field applications are discussed by Cole et al. 1988 and Gupta et al. 1987 (i.e., 11 field applications are described in Chapter 6 of Cole et al. 1988). Since it was released in 1988, CFEST-SC has been applied to other field sites in the United States and Japan by Battelle and other consulting engineering firms.

Programming Considerations

CFEST is written in FORTRAN and will compile and execute on a variety of unix computers (e.g., Silicon Graphics, Sun Microsystems, and IBM workstations), on the CRAY X-MP/UNICOS systems, and on DEC VAX/VMS systems.

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5.3 GENII

The Hanford Environmental Dose System (Generation II or GENII) includes the second generation of Hanford environmental dosimetry computer codes. This coupled system of computer codes was developed as part of the Hanford Environmental Dosimetry Upgrade Project and incorporates the internal dosimetry models recommended by the International Commission on Radiological Protection (ICRP) (ICRP 1977; 1979) in updated versions of the environmental pathway analysis models used at Hanford.

The GENII system provides a technically peer-reviewed, documented set of programs for calculating radiation doses from radionuclides released to the environment. The seven linked computer codes and associated data libraries contained in GENII perform essentially the same calculations as found in previous radiation dosimetry programs. The core system of GENII can calculate annual doses, dose commitments, or accumulated doses from acute or chronic releases of radioactive materials to air or water. These calculations were previously supplied by the computer codes KRONIC (Streng and Watson 1973), SUB-DOSA (Streng et al. 1975), DACRIN (Houston et al. 1974; Streng 1975), ARRRG (Soldat et al. 1974), FOOD (Baker 1977; Baker, et al. 1976), and PABLM (Napier et al. 1980). GENII also can calculate annual doses, dose commitments, and accumulated doses from initial contamination of soil or surfaces, thus incorporating capabilities from PABLM and ONSITE/MAXI (Kennedy et al. 1986, 1987; Napier et al. 1984). A limited biotic transport capability is included that can simulate the results of BIOPORT/MAXI (McKenzie et al. 1985). GENII contains a modified version of the shielding code ISOSHL (Engle et al. 1966; Simmons et al. 1967) that creates factors relating sources with various geometries to dose rates. An essentially unchanged version of DITTY (Napier et al. 1986) has been added for predicting doses from waste management operations to the public during periods as long as 10,000 years.

The documentation for GENII consists of three volumes. Volume 1 describes the theoretical considerations of the system, including the conceptual diagrams, mathematical representations of the solutions, and descriptions of solution techniques. Volume 2 is a User's Manual providing code structure, user's instructions, required system configurations, and QA-related topics. Volume 3 is a code Maintenance Manual for the serious user, including code logic diagrams, a global dictionary, worksheets and example hand calculations, and listings of the code and its associated data files.

Assumptions and/or Limitations

The assumptions and/or limitations that apply to the GENII system are nearly identical to those described for the first generation dosimetry codes that have been incorporated in this package. Readers are therefore referred to the detailed descriptions of these codes listed separately in Appendix B.

GENII was developed under a QA plan based on the ANSI standard NQA-1 and has undergone two external peer reviews. All steps of the code development have been thoroughly documented and tested. Worksheets and example hand calculations have been provided in the documentation for GENII.

Programming Considerations

GENII is written in FORTRAN and operates on IBM and compatible personal computers (requires a math coprocessor).

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5.4 MAGNAS3

MAGNAS3 (Multiphase Analysis of Groundwater, Non-aqueous phase liquid And Soluble component) is a three-dimensional numerical code that simulates the flow of groundwater, non-aqueous phase liquid (NAPL), and air (or vapor) through porous media in three dimensions. The MAGNAS3 code may be used to simulate the flow of air as a fully active phase, rather than assuming that the air phase is passive. In addition the transport of a dissolved constituent may also be simulated. The transport simulation capability in the code accounts for the advection and hydrodynamic dispersion in all fluid phases, equilibrium sorption, volatilization, dissolution, precipitation and first-order degradation. A variety of more simplified flow formulations may be simulated as subsets of the most general fully three-phase modeling approach. Such formulations include pseudo-three-phase (with a passive air phase), two-phase (NAPL-water) flow, and two-phase air-water flow.

Assumptions and/or Limitations

- Flow of the fluid phases is considered isothermal and governed by Darcy's law.
- Each fluid phase is considered slightly compressible (except for gases which are considered compressible), homogeneous and immiscible with the other fluid phases for the flow calculations.
- Transport is governed by Fick's law.
- Adsorption and decay of the solute may be described by a linear equilibrium isotherm and first-order decay rate, respectively.
- Kinetic sorption effects and reversible chemical reactions are not included.

Programming Considerations

MAGNAS3 is proprietary to HydroGeoLogic, Inc. Hence, the software must be obtained from HydroGeoLogic, Inc. Only the executable will be distributed to protect the proprietary interests of HydroGeoLogic, Inc.

The source code was developed and tested on personal computers using the University of Salford and Lahey FORTRAN77 compilers, and has been implemented on IBM, MIPS and SUN workstations with standard FORTRAN77 compilers.

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5.5 MEPAS

The Multimedia Environmental Pollutant Assessment System (MEPAS) is a fully coupled assessment model developed for DOE to estimate public health risks for ranking applications. Developed by Pacific Northwest Laboratory for screening and ranking of environmental problems, MEPAS is designed for site-specific assessments using readily available information to estimate potential health impacts. The model was developed to cover a wide range of potential problems and regulatory issues at DOE sites in various stages of site characterization. MEPAS is a code that can be used to facilitate risk assessments as part of the RI/RA/FS and ER processes. MEPAS is a user-friendly, physics-based, personal computer (PC) model that allows an integrated, site-specific, multimedia environmental assessment using readily available information. MEPAS is based on standard approaches and EPA's general guidance for the RI/FA/FS process. The unique feature of MEPAS is the integration of these computations into a single-analysis system.

MEPAS is a physics-based risk computation code that integrates source-term, transport, and exposure models. Contaminant source-to-receptor analyses can be conducted through all major transport pathways and exposure routes. The source is a point in space and time where contaminants may be released into the environment. Examples include trenches, leaking underground storage tanks, stacks, landfills, ponds, lagoons, and tile fields. The transport pathway is the environmental medium (e.g., groundwater, surface water, overland, and air) through which a contaminant can migrate from a source. The exposure route is the mode in which a sensitive receptor is exposed to a contaminant. Exposure routes include food-chain considerations and physical contact by humans through inhalation, ingestion, dermal contact, and external dose (for radionuclides only). Risk values are computed for chemical and radioactive carcinogens; while hazard quotients, based on reference doses, are computed for noncarcinogens. For carcinogenic pollutants, estimates of risk to the exposed population are also generated.

A chemical database is provided with the MEPAS methodology to supply all the needed information for each constituent to be evaluated. The MEPAS database (Streng and Peterson 1989) currently contains chemical properties and constants for nearly 500 chemicals and radionuclides. The database contains information on pollutant identification (name and Chemical Abstract Service registration number) and properties describing physical

characteristics (e.g., solubility, vapor pressure, distribution coefficient model parameters), environmental degradation for chemicals (e.g., first-order degradation rates) and decay for radionuclides (e.g., half-lives and decay products [Kocher 1979]), environmental transfer factors, radiological dosimetry factors, and chemical toxicity.

Assumptions and Limitations

- Radiation dose factors are based on ICRP Publication 30 internal dosimetry models (ICRP 1979-1988).
- Analyses may be performed for chronic release cases; acute releases are not included in the current version.
- The stack/vent characteristics for point-source, emission-rate calculations include radius, exit temperature and velocity, stack height, and building height for wake effects.
- Wind and mechanical suspension emissions are based on Cowherd et al. (1984).
- Five types of volatilization emissions are based on Thibodeaux (1989) and EPA (1988).
- Transport and dispersion are computed in terms of a sector-averaged Gaussian dispersions model (Busse and Zimmerman 1973; Culkowski 1984).
- Deposition is computed as the sum of outputs from empirical wet and dry deposition algorithms (Van Voris et al. 1984).
- The agricultural ingestion routes include leafy vegetables, other vegetables, meat, and milk using standard exposure pathway models and parameters (NRC 1977, Streng et al. 1987, Kennedy and Streng 1992).
- Chemical toxicity is evaluated using the EPA slope factor (for carcinogens) and reference dose (for non-carcinogens) methods.

Programming Considerations

The user interface shell including data capture and storage programs are written in compiled dBASE III Plus, and the MEPAS transport and exposure assessment programs are written in FORTRAN. A new interface shell is under development written in Microsoft Visual Basic. An IBM or 100% compatible PC (with 640-KB RAM, 20-MB hard disk) is required. A math co-processor is not required but will significantly improve the model performance. MEPAS is a file-based application, and all data are stored and exchanged between major components by file input/output to ensure user access to all intermediate data.

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Sources

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5.6 MSTS

The Multiphase Subsurface Transport Simulator (MSTS) contains a continuum model of air, water, energy, and dilute species conservation. It was written for assessment of the postclosure performance of a potential high-level nuclear waste repository at Yucca Mountain, Nevada, and has been used in barrier studies for the Hanford Site. The fundamental purpose of MSTS is to produce numerical predictions of two-phase (aqueous and gas), two-component (air and water) thermal and hydrologic flow and transport phenomena in variably saturated subsurface environments, which are composed of unfractured and/or highly fractured porous media. Available secondary processes include binary diffusion and vapor pressure lowering.

Transport processes are described by four governing conservation equations (air mass, water mass, energy, and dilute species mass conservation) and associated constitutive functions. These governing conservation equations are discretized for a heterogeneous, anisotropic porous media to algebraic form with an integrated finite difference method. Discretization has been implemented in MSTS for one, two, or three dimensions for two orthogonal computational grid systems; Cartesian or axisymmetric cylindrical. The nonlinear discretized equations are converted to a linear form using a multivariable, residual-based Newton-Raphson iteration technique. Any combination of one, two, or all three of the air, water, and energy equations may be chosen for fully coupled solution to suit the needs of the problem under consideration. The dilute species mass conservation equation is solved sequentially with the coupled equations.

Assumptions and/or Limitations

The following assumptions have been incorporated in the MSTS program:

- The porous media and fluids are a continuum that are at least piecewise continuous.

- Mass advective fluxes from pressure gradients and gravitational body forces follow Darcy's flow equations for aqueous and gas phases.
- Diffusion of components through the gas phase occurs according to Fick's law modified for porous media with soil tortuosity parameters.
- Interphase mass transfer of water between the aqueous and gas phases depends on an assumption of thermodynamic equilibrium.
- Solubilities of air within the aqueous phase follow Henry's law for chemical equilibrium.
- Heat transport within the subsurface environment occurs by thermal diffusion and advection.
- Solid and aqueous phase pathways for thermal diffusion are considered; thermal diffusion through the gas phase is neglected.
- Both sensible and latent advection of thermal energy are considered.
- Only one dilute species, with or without radioactive decay, may be modeled at a time.
- Specie transport through the subsurface environment occurs by diffusion, dispersion, and advection. Species diffusion, dispersion, and advection are combined into a single transport coefficient with a power-law approximation to the exact solution.
- Liquid and water-vapor properties are computed from the International Formulation Committee's steam table functions, and air properties are computed from empirical functions.
- The porous media and the fluid are slightly compressible, permitting the equations to be derived for a nondeforming coordinate system.
- Adsorption and desorption are the only chemical processes described, and equilibrium is assumed.
- Liquid saturation is computed using nonhysteretic empirical functions dependent on gas-aqueous capillary pressures, where the gas-aqueous capillary pressure equals the difference between the gas- and aqueous-phase pressures.
- Liquid relative permeability and gas relative permeability are computed using nonhysteretic empirical functions dependent on liquid saturation.
- A linear isotherm is assumed to describe the adsorption/desorption process.

Programming Considerations

The MSTS Version Beta Release 0002 source code is written in FORTRAN 77, following the American National Standard Institute's (ANSI) standards, and is essentially machine-independent (Environments used to date with MSTS include a CRAY supercomputer, IBM RISC, Sun, Silicon Graphics, and Convex workstations, and IBM PC and Macintosh desktop computers). MSTS features a well-ordered, human-readable input file format which can be generated using the MSTS Graphical Input, a graphical user interface available for the Macintosh environment to provide efficient input file preparation and editing capabilities. Program parameterization is easily accomplished at compilation through a short include file that can be customized to suit the size of the problem to be solved, and the include file can be automatically generated by the MSTS Graphical Input. A restart capability is included in the code. Both a theory manual and a user's guide and reference for the code have been published.

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5.7 ORIGEN2

ORIGEN2 is a versatile point depletion and decay program for use in simulating nuclear fuel cycles and calculating the nuclide compositions of various nuclear materials. The original ORIGEN program (Bell 1973) was designed for use in generating spent fuel and waste characteristics (composition, thermal power, etc.) that would form the basis for the study and design of fuel reprocessing plants, spent fuel shipping casks, waste treatment

and disposal facilities, and waste shipping casks. Enhancements appearing in ORIGEN2 include (1) substantial changes to the input/output and control features of the computer program, (2) the inclusion of relatively sophisticated reactor physics calculations for different reactor/fuel combinations, and (3) calculation of spectrum-weighted cross sections and fission product yields for approximately 860 nuclides.

ORIGEN2 uses the matrix exponential method to solve a large system of coupled, linear, first-order ordinary differential equations with constant coefficients. The matrix exponential technique was developed to solve a nonhomogeneous system of equations, which makes it possible for ORIGEN2 to be used in calculating the accumulation of radioactivity in processing plants, in waste disposal operations, and in the environment.

Assumptions and/or Limitations

The following assumptions and/or limitations apply to the ORIGEN2 program:

- Nuclear transmutation and decay are represented as a simultaneous system of linear, homogeneous, first-order ordinary differential equations with constant coefficients.
- The build-up and depletion of nuclides during irradiation is calculated using zero-dimensional (i.e., point) geometry and quasi-one-group neutron cross sections. This means that ORIGEN2 cannot account for spatial or resonance self-shielding effects or changes in the neutron spectrum other than those initially encoded.
- Elemental chemical toxicity used in ORIGEN2 are from Dawson (1974).

Programming Considerations

ORIGEN2 is written in FORTRAN, and versions are available that run on IBM and CDC-compatible computers. A separate user's manual for ORIGEN2 is documented in Croff (1980a,b). An extensive library of nuclear data (half-lives and decay schemes, neutron absorption cross sections, fission yields, disintegration energies, and multigroup photon release data) is included with the program.

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5.8 PORFLO-3

Version 1.2 of the PORFLO-3 computer code embodies a model of steady or transient nonisothermal flow and transport of a dissolved species within a continuous fluid phase in a variably saturated, heterogeneous, anisotropic, fractured porous continuum. The PORFLO-3 code is in some sense an extension of the two-dimensional PORFLO model to three dimensions and variable saturation. However, testing and applications of PORFLO-3 have typically been focused on problems involving isothermal flow and solute transport in the vadose (unsaturated) zone and sedimentary aquifers, whereas the two-dimensional PORFLO model was largely applied to buoyancy driven flow and transport in saturated basalts.

PORFLO-3 simulations generally provide numerical solutions to coupled boundary value problems involving fluid flow, heat transfer, and mass transport. The governing equations are derived from the principles of conservation of mass, momentum, and energy in a stationary control volume. The control volume is assumed to contain a heterogeneous, anisotropic porous medium. Discrete one-dimensional and two-dimensional features of the medium (e.g. fractures, clastic dikes) can be represented in a single effective continuum, or can be distinguished explicitly as lower-dimensional embedded elements. Coupling of the governing equations is through time-varying parameters.

The method of nodal-point integration is used to discretize the governing equations over a nonuniform grid in either cartesian or cylindrical coordinates. The resulting algebraic analogues for one-, two- and three-dimensional problems are solved by a variety of techniques such as the alternating direction implicit method, Choleski decomposition, Point Successive Over-Relaxation, Reduced System Conjugate Gradient, and various other iterative solvers. The gradient and iterative solvers were added particularly for use with the nonlinear equation governing flow in an unsaturated domain, but are applicable to the other governing equations as well. In the coupled mode, the governing equations are solved sequentially at each time step beginning with the fluid flow equation followed by the heat transfer equation and ending with the mass transport equation. The equations can as well be uncoupled and can be solved individually or pairwise.

Assumptions and/or Limitations

The following assumptions are inherent in the PORFLO-3 model:

- The matrix of the porous medium, the infilling fluid phase, and the air phase occupying unfilled void spaces are each assumed to be continuous.
- The porous medium and the fluid are only slightly compressible so that the governing equations can be derived in a fixed (rather than deforming) coordinate system.
- The fluid velocity is small so that inertia terms are negligible and Darcy's law is applicable.
- Variation of fluid density and viscosity with fluid pressure is negligibly small.
- Effective hydraulic conductivity and specific storage are functions of pressure head.
- Variations in the porosity of the porous medium as a result of stress changes have been ignored.
- Heat and mass transport caused by Dufour and Sorret effects, respectively, are negligible.
- Dispersive heat and mass transport can be described by a linear gradient law.
- The porous medium and the fluid are in thermal equilibrium at all times.
- Adsorption and desorption (due to various chemical/physical processes) are assumed to occur rapidly so equilibrium is attained instantaneously.
- A linear isotherm is assumed to describe the adsorption/desorption process.
- *Verification/Validation Studies.* PORFLO-3 has been tested by comparing simulation results with (1) analytic solutions, (2) results from independently developed numerical models, and (3) field data. Independent verification and benchmark testing was first performed for Version 1.0 of PORFLO-3 by Magnuson et al. (1990). A validation exercise for unsaturated flow was conducted with Version 1.1 by Rockhold and Wurstner (1991). The latest formal testing of Version 1.2 (Kline 1993) relies in whole upon tests developed for predecessor versions to demonstrate consistency of results through generations of versions. Other more focused and/or application specific testing has been performed but not specifically documented in a form for publication. Moreover, some significant comparisons of simulated results to field observations are performed in the course of analytical work and are documented unceremoniously in reports of those studies (e.g., Appendix D of WHC 1990; Appendix J of Singleton and Lindsey 1994).

Programming Considerations

PORFLO-3 is written in ANSI Standard FORTRAN77 and operates on a variety of computers. In the past two years, Version 1.2 of PORFLO-3 has been operated successfully on CRAY, IBM RISC, SGI, SUN, 486 and 386 computers at Westinghouse Hanford Company.

Documentation

A users manual for PORFLO-3, independent of any particular computer or operating system, is provided by Runchal et al. (1992). The companion theory manual was prepared for Version 1.0 (Sagar and Runchal 1990), and is applicable to the current Version 1.2.

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Sources

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5.9 PORFLOW

Version 2.394gr of the PORFLOW code is a multiphase version of the PORFLOW code and was adapted for the Hanford Grout Performance Assessment. PORFLOW solves a set of coupled transport equations for fluid velocities, pressures, temperature, and concentration of chemical species (up to four) in multi-phase or multi-fluid, variably saturated, fractured or porous media flow.

Assumptions and/or Limitations

These are the same as version 1.2 except that air can be modeled as an active phase, instead of passive.

Programming Considerations

PORFLOW, version 2.394gr, is written in FORTRAN77 and has been implemented on a variety of computers including the Cray and the IBM, SGI, and SUN workstations at Westinghouse Hanford Company.

The code is licensed non-exclusively to Westinghouse Hanford Company by Analytic & Computational Research, Inc. (ACRI) for use in projects sponsored by the United States government. Copies which are provided through ACRI to other government contractors are licensed only by ACRI.

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5.10 RADTRAN 4

RADTRAN 4 is used to evaluate possible health and economic impacts associated with the transportation of radioactive materials. The program uses a combination of meteorological, demographic, health physics, transportation, packaging, and material factors to analyze risks associated with both normal transport (incident-free) and various user-selected accident scenarios. RADTRAN 4 is an update of the RADTRAN 3 computer code discussed in earlier versions of this document.

The RADTRAN 4 program consists of seven submodels 1) a material model that allows users to select basic material parameters including number of curies of each isotope per package, average total photon energy per disintegration, the rate at which released material is deposited on the ground, cloudshine dose factors, the physical character of the waste, half-life, and measures of the radiotoxicity of the dispersed material; 2) a transportation model that considers accident rates for each transportation mode (truck, van, rail, cargo and passenger air, barge, and ship), traffic patterns (fraction of travel occurring on various road types, through different population zones, and under both rush-hour and

normal traffic conditions), and basic shipment information (number of crew per vehicle, handling and storage times, duration and number of stops); 3) an accident severity and package release model that classifies accidents according to severity (i.e., fire; crush, impact, and puncture forces) and defines the respirable fraction (particles $< 10 \mu\text{m}$) of airborne material released from packages; 4) a meteorological dispersion model that describes the diffusion of a cloud of aerosolized debris released during an accident; 5) a population distribution model that describes the distribution and relative densities of people in three population zones (rural, suburban, and urban), and in certain specific areas, such as pedestrian walkways, warehouses, and air terminals; 6) a health effects model^(a) that evaluates the radiotoxicity of materials in terms of potential for producing acute fatalities, early morbidities, genetic effects, and latent cancer fatalities; and 7) an optional economic model that evaluates the economic impacts connected with surveillance, cleanup, evacuation, and long-term land-use denial activities.

The new features of RADTRAN 4 include the following:

- Ability to perform link-by-link route-specific analyses
- Addition of an internal radionuclide library
- Improved logic for multiple-radionuclide packages
- Allows for separate treatment of gamma and neutron exposures
- Allows definition of up to 20 accident severity categories

Perhaps the most significant new feature is the capability to perform route-specific analyses. Up to 40 separate transportation "links" or route segments may be defined. Each link may incorporate route-specific parameters, such as population density, vehicle velocity, accident rate, segment length, transport mode, and zone designation (rural, suburban, or urban). Aggregate data may still be utilized, if desired.

The radiological impacts from transportation accidents are expressed according to the level of consequence, probability of occurrence, and level of risk. A risk figure-of-merit is calculated by summing the products of the probability of each specific accident and its associated level of consequence.

(a) This model does not incorporate BEIR V or ICRP 60 health effects conversion factors. The authors recommend obtaining results as dose risks and applying BEIR V or ICRP 60 health effects conversions to them.

Assumptions and/or Limitations

The following assumptions have been incorporated in the RADTRAN 4 program:

- Dose calculations in the population exposure model assume that the package or shipping cask is a point source or line source of radiation (line-source is used for handlers who work in close proximity to packages; point-source used elsewhere).
- Radioactive materials released from a package during an accident are assumed to be dispersed according to standard Gaussian puff-type models. However, the user may define alternative dispersion factors if desired.
- External radiation exposures from ground contamination are calculated using an infinite plane source model.
- *Verification and/or validation studies.* Sensitivity analyses have been performed for several applications (i.e., incident-free transportation, vehicular accidents) of the RADTRAN III program and are documented in Neuhauser and Reardon (1986) and Madsen et al. (1986).

RADTRAN 4 is in compliance with ANSI/IEEE 730-89 for software quality assurance and all benchmarking is documented in the accompanying software verification and validation plan.

Programming Considerations

A user's manual (Neuhauser and Kanipe 1992) documents the various options for generating accident scenarios and provides additional instructions for computer operators.

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Sources

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5.11 RESRAD

The RESRAD program was developed at the Argonne National Laboratory for the United States Department of Energy to compute site specific residual radioactive contamination guidelines. Such guidelines are also known as cleanup criteria. Radiation dose and excess lifetime cancer risks to an individual living in the residual contamination may also be computed.

The program is easy to use, and offers numerous data entry screens. The user must supply site specific parameters or use the default values. The categories and examples of parameters are listed below.

Contaminated Zone Parameters - area and thickness of waste site, decay times

Hydrological Parameters - soil thickness, density, porosity, diffusion coefficients, hydraulic conductivity, evapo-transpiration coefficient, precipitation & irrigation amounts, runoff coefficient

Geochemical Parameters - distribution coefficients for each nuclide, leach rates and solubility

External Exposure Parameters - shape factors, shielding factor, exposure time

Inhalation Parameters - inhalation rate, mass loading, dilution length, exposure time

Ingestion Parameters - consumption rates for vegetation, milk, meat, fish, drinking water, and incidental soil, contamination fractions, cattle diet parameters

Radon Parameters - thickness, density, porosity, water content and radon diffusion coefficients for the soil cover and building foundation, also average wind speed and building air exchange rate

The current version is numbered 5.0, and dated March 11, 1994. The program handles radioactive decay during all steps of the transport and dose processes. This version also enables the user to perform sensitivity studies in which one parameter at a time is calculated at extreme values to see what effect it has on the final dose or concentration guideline.

Assumptions and/or Limitations

The RESRAD program makes a number of simplifying assumptions to speed calculations. The principle ones known to the current contact are shown below.

Radioactive Decay - decay chains are shortened by combining short lived daughters with parents. It is assumed that the daughters will be in equilibrium in the soil and in all food products consumed. This assumption breaks down for the milk pathway, because the milk is consumed within a few days after the cow eats the grass so the decay chains do not have time to return to equilibrium. Plant and animal uptake factors for alpha emitting nuclides differ widely. Of particular concern is the milk pathway for Th-228, the dose from which may be underestimated by an order of magnitude.

Soil-to-Plant Concentration Ratios - Most programs (eg. GENII and PATHRAE) recognize two separate ratios: one for the plant foliage and the other for the fruits and grains (reproductive portions). The authors of RESRAD combined the two values into one to represent all plant types and structures. This results in small differences with codes such as GENII and PATHRAE.

Site Specific Data - The Hanford Environmental Dose Overview Program (HEDOP) has defined site specific data suitable for most environmental work at the Hanford Site. Other parameters have not been standardized. These should be properly justified and brought to the attention of the HEDOP for general use site wide.

Verification/Validation Studies

The RESRAD program uses standard regulatory models such as are used by the NRC and EPA when evaluating applications. What is unique about RESRAD is the combination of models and the selection of default parameters.

The program has been compared with 6 other programs, including GENII. The results of these comparisons were published informally as a working document for review. The comparisons show large differences in some cases, but the differences are not satisfactorily explained in the document.

Programming Considerations

The RESRAD program is only available for IBM compatible personal computers with a hard disk. The program requires about 2.5 Mbyte on the hard disk. Optional accessories are the math coprocessor and a mouse. The program is easily installed by means of self-extracting archive files.

Documentation

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5.12 STOMP

The STOMP (Subsurface Transport Over Multiple Phases) engineering simulator is currently being developed for the U.S. Department of Energy, Office of Environmental Restoration and Waste Management in conjunction with the Volatile Organic Compounds in Arid Soils Integration Demonstration Program (ARID-ID). The ARID-ID program is directed towards the remediation of sites where the subsurface environment has been contaminated with volatile organic compounds and/or radioactive material. The STOMP engineering simulator provides a variety of capabilities to evaluate subsurface remediation technologies. Specifically the engineering simulator has been designed to provide engineers and scientists with multidimensional analysis capabilities of subsurface flow and transport phenomena for multiple phase and nonisothermal systems in saturated or partially saturated environments. The engineering simulator offers a variable source code configuration, which allows the user to optimize the source code, in terms of execution speed and memory, to the specifics of the subsurface system under consideration. Construction of the variable source code and input files may be performed through an associated interactive graphical user interface.

The engineering simulator employs an integrated-volume finite-difference approach for the physical domain and a backwards Euler approach for the time domain to discretize the governing partial differential conservation equations. Coupled solutions of component mass and energy conservation equations over three immiscible phases (aqueous, gas, and nonaqueous liquid) are possible. Solute transport problems with equilibrium partitioning between four phases (aqueous, gas, nonaqueous liquid, and solid) may be solved for multiple solutes with radioactive decay. The solute transport equations are solved sequentially to the coupled flow and heat transport equations, therefore requiring the assumption of dilute concentrations. Nonlinearities in the discretized coupled flow and heat transport equations are resolved with a Newton-Raphson iteration scheme. Phase appearances and transitions are handled through variable switching schemes. The

saturation-relative permeability-pressure constitutive theory for describing both two-phase (water-air) and three-phase (water-oil-air) systems include fluid entrapment and hysteretic effects. The simulator allows a variety of boundary conditions, both internally and externally with respect to the computational domain. The simulator allows computation domains with both permanent and dynamically defined inactive nodes. The simulator currently provides two linear system solvers, a directed banded scheme and an iterative conjugate gradient algorithm.

Assumptions and/or Limitations

The following assumptions have been incorporated into the STOMP engineering simulator:

- Fluid flow through the subsurface follows Darcy's law for porous media.
- Coordinate systems are currently restricted to Cartesian or cylindrical, with plans to extend the capabilities to orthogonal boundary fitted grid systems.
- Thermodynamic and chemical equilibrium exists within a computational cell.
- Dissolution of water and air components within the nonaqueous liquid phase is negligible.
- Diffusion of components and solutes through the aqueous, gas, and nonaqueous phases follows Fick's law modified for porous media.
- Hydrodynamic dispersion of components and solutes functionally depends on the phase pore velocity.
- Gas-phase properties of density, viscosity, and component diffusion coefficients are functions of the gas composition, pressure, and temperature.
- Aqueous- and nonaqueous-phase properties are independent of composition, but dependent on pressure and temperature.
- The saturation-relative permeability-pressure constitutive theory for three-phase systems assumes a wettability order of water-oil-air.
- The aqueous phase is assumed to never totally disappear through a vapor-pressure lowering function.
- All fluid phases and the porous media are considered compressible.
- The rock/soil density and specific heat remain constant.
- Viscous dissipation with respect to the energy equation is neglected.

- The properties of intrinsic permeability and thermal conductivity are collinear with the axes, but may contain anisotropy.

Programming Considerations

STOMP has a variable configuration source code written in FORTRAN 77 with a variety of timing procedural calls for numerous computing platforms.

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5.13 TRANSS

TRANSS contains a simplified groundwater transport model and can be used to estimate the rate of migration of a decaying radionuclide that is subject to sorption governed by a linear isotherm. TRANSS employs simple analytical solutions of the advection-dispersion equation to describe solute movement along a collection of hydrologic streamlines composing a hypothetical streamtube. Local dispersion along a streamtube is treated as a combination of advection and Fickian diffusion, based on an effective dispersion coefficient.

Contaminant release from a source is described in terms of a fraction-remaining curve provided as input information. An option in the program allows for the calculation of a fraction-remaining curve based on four specialized release models (1) constant release rate, (2) solubility-controlled release, (3) adsorption-controlled release, and (4) diffusion-controlled release from beneath an infiltration barrier.

Assumptions and/or Limitations

The following assumptions have been incorporated in the TRANSS program:

- It is assumed that contaminant transport can be represented by a collection of one-dimensional problems defined by the streamlines of a flow field under steady-state conditions.

- Transverse dispersion within a streamtube is assumed to be negligible.
- Travel times along streamlines must be obtained from a prior groundwater flow simulation.
- TRANSS is not a predictive program. The program is intended to be used as a scoping tool for estimating the relative influence of transport controlling parameters. Moreover, output estimates depend conditionally on the specific groundwater flow field used as input.
- *Verification and/or validation studies.* TRANSS has been verified for a number of sample problems, including well-documented test cases involving the transport of single radionuclides (Simmons and Cole 1985).

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5.14 UNSAT-H

UNSAT-H contains a hydrologic model for simulating water and heat flow in unsaturated soils and is used primarily for assessing the water and energy dynamics of arid sites under consideration for near-surface waste disposal. The program can be used to predict deep drainage (i.e., recharge) as a function of environmental conditions such as climate, soil type, and vegetation. An additional application includes the simulation of various waste management practices, such as placing surface barriers over waste sites.

UNSAT-H employs a one-dimensional, mechanistic model that simulates the dynamic processes of infiltration, drainage, redistribution, surface evaporation, uptake of water from soil by plants, energy exchange between the soil surface and the overlying atmosphere, and the flow of heat within the soil. The mathematical basis of the model is Richards'

equation of water flow, Fourier's law of heat conduction, and Fick's law of diffusion. The basic numerical implementation is patterned after the UNSAT model of Gupta et al. (1978).

UNSAT-H uses a fully implicit, finite-difference method for solving the water and heat transport equations. Plant water uptake is introduced as a sink term at each node and is calculated as a function of root density, water content, and potential evapotranspiration. The simulated soil profile can be homogeneous or layered. The boundary conditions can be controlled as either constant head or flux conditions depending on the specific conditions at a given site.

Features of UNSAT-H Version 2.0 that are improvements over the original UNSAT and earlier versions of UNSAT-H include a cheatgrass transpiration function, additional options for describing soil hydraulic properties, consideration of heat and nonisothermal vapor flow, direct calculation of evaporation, and reduction of mass-balance error.

Output from UNSAT-H consists of the following: (1) hourly or daily summaries of water content, water potential, water and heat fluxes, temperature, and plant water use as a function of depth, and (2) cumulative totals of the water and heat balance components (storage, precipitation, evaporation, transpiration, drainage, net radiation, sensible heat, latent heat).

Assumptions and/or Limitations

The following assumptions have been incorporated in the UNSAT-H program:

- Water and heat flows in one dimension.
- Richard's equation, Fourier's law, and Fick's law are valid.
- Liquid water flow is not induced by temperature gradients.
- Air phase is continuous and at constant pressure.
- Soil hydraulic properties are independent of soil temperature.
- Soil hydraulic properties are unique (i.e., not hysteretic).
- Plant growth, development, and transpiration can be described empirically.
- Precipitation and evaporation are not affected by snow cover and snowmelt.
- *Verification and/or validation studies.* Successful verification tests of the processes of infiltration, redistribution, and drainage have been performed using UNSAT1D (see Simmons and Cole 1985), a precursor model of UNSAT-H. The UNSAT-H model has been tested using measured field data from the 200-Area closed-bottom lysimeter (Fayer et al. 1986, Appendix B). Fayer and Jones (1990) contains verification tests for the processes of infiltration, redistribution, and drainage and for heat flow. Baca

and Magnuson (1990) contains four verification and four benchmark test cases that cover both water and heat flow scenarios in both homogeneous and layered media. Fayer et al. (1992) contains comparisons of model output and field data collected from lysimeters in the 200 Area of the Hanford Site.

Programming Considerations

UNSAT-H Version 2.0 is written in VAX FORTRAN Version 4.7 and runs under the VAX/VMS Version 4.7 Operating System. The UNSAT-H Version 2.0 code has been modified to run on DOS and UNIX machines also. This extended version is called Version 2.01.

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5.15 VAM3DCG

VAM3DCG (Variably Saturated Anal^ysis Model in 3 Dimensions with Preconditioned Conjugate Gradient Matrix Solvers) contains a continuum model of water and dilute species conservation. The VAM3DCG program is proprietary to HydroGeoLogic, Inc. It was originally developed for the U.S. Nuclear Regulatory Commission.

VAM3DCG is a three-dimensional, finite element code developed to simulate moisture movement and solute transport in variably saturated porous media. The code is capable of simulating a wide range of conditions commonly encountered in the field. Simulations can be performed efficiently for fully three-dimensional, two-dimensional, or axisymmetric problems. Both flow and transport processes are handled concurrently or sequentially. Material heterogeneities and anisotropy are handled by taking advantage of the finite element approach. Efficient matrix computation and solution schemes are employed in conjunction with simple rectangular prism elements or hexahedral orthogonal curvilinear elements, to analyze problems involving highly nonlinear, hysteretic/nonhysteretic soil moisture characteristics. Many types of boundary conditions can be accommodated including: (1) water table conditions, (2) atmospheric conditions associated with seepage faces, evaporation and nonponding infiltration, (3) water uptake by plant roots, 4) vertical recharge of the water table, and (4) pumping and injections wells.

Assumptions and/or Limitations

The following assumptions have been incorporated in the VAM3DCG program:

- Water is the only flowing fluid phase (i.e., the air phase is assumed to be inactive).
- Flow of the fluid phase is considered isothermal and governed by Darcy's law.
- The fluid is considered slightly compressible and homogeneous.
- Transport in the porous medium system is governed by Fick's law. The hydrodynamic dispersion coefficient is defined as the sum of the coefficients of mechanical dispersion and molecular diffusion. The medium dispersivity is assumed to correspond to that of an isotropic medium, where α_L and α_T are the longitudinal and transverse dispersivities.
- Adsorption and decay of the solute may be described by a linear equilibrium isotherm and a first order decay rate, respectively.
- In performing a variably saturated flow analysis, the code handles only single-phase flow (i.e., water) and ignores the flow of a second phase (i.e., air or other nonaqueous phase) which, in some instances, can be significant.
- Flow and transport in fractures are not taken into account.

- The code does not take into account kinetic sorption effects and/or reversible chemical reactions which, in some instances, can be important.

Programming Considerations

VAM3DCG is proprietary to HydroGeoLogic, Inc. Hence, the software must be obtained from HydroGeoLogic, Inc. Only the executable will be distributed to protect the proprietary interests of HydroGeoLogic, Inc. Code alterations to meet special needs, and resizing of parameters and arrays within the code, must be negotiated with HydroGeoLogic, Inc.

There is no graphical user interface for VAM3DCG; it relies on a highly formatted input file developed by the user using a text editor and the standards set forth in the documentation to control the code's operation and to provide input parameter values. A grid generator utility (also proprietary to HydroGeoLogic, Inc.) is in development for Unix environments and is of limited use in preparation of input grids and assignment of boundary conditions.

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6.0 Statutory and Regulatory Requirements

The Hanford Site is owned by the U.S. Government and is managed by the U.S. Department of Energy (DOE). It is the policy of the DOE to carry out its operations in compliance with all applicable federal laws and regulations, state laws and regulations, presidential executive orders, and DOE orders. Environmental regulatory authority over the Hanford Site is vested both in federal agencies, primarily the U.S. Environmental Protection Agency (EPA), and in Washington State agencies, primarily the Washington Department of Ecology (Ecology). Significant environmental laws and regulations are discussed in this chapter. First, major federal environmental laws are listed; then, significant applicable federal and state regulations are discussed; and finally, DOE orders, permits, and some specific regulations for the environmental protection of the public are discussed.

[The following introduction (italicized text) is intended to be explanatory for persons writing a Chapter 6.0 for a Hanford Site EIS, but is not intended to be included in the EIS.]

Introduction

The regulations of the Council on Environmental Quality (CEQ) in the Code of Federal Regulations (CFR) at 40 CFR 1500-1508 implement the National Environmental Policy Act (NEPA) and set forth requirements for the preparation of environmental documentation by federal agencies. The CEQ regulations develop the NEPA process and focus on the environmental impact statement (EIS). The CEQ regulations identify the types of actions proposed by a federal agency that require preparation of an EIS, prescribe the content of an EIS, and identify actions and other environmental reviews that must or should be undertaken by the federal agency in preparing and circulating an EIS. In general, an EIS must be prepared by a federal agency for any major federal action significantly affecting the quality of the human environment (40 CFR 1502.3).

A specific requirement in the CEQ regulations (40 CFR 1502.25) is that the EIS must list "all Federal permits, licenses, and other entitlements which must be obtained in implementing the proposal." There is, however, no requirement in the CEQ regulations that the EIS must list or discuss applicable environmental laws and regulations. Nevertheless, applicable environmental laws and regulations have been discussed in recent Hanford Site EISs, and Chapter 6.0 of these EISs has evolved into a chapter on "Statutory and Regulatory Requirements." Given the large number of applicable environmental regulations and the rapidly changing character of environmental regulation, this practice is likely to continue.

The purpose, then, of this document is to present a "reference" Chapter 6.0 that can be used in the preparation of future Hanford Site EISs. The intent here is to present a rather inclusive discussion of federal and state environmental laws, regulations, and permits that are applicable to activities at the Hanford Site. The information in this chapter can then be adapted to any future Hanford Site EIS simply by deleting the irrelevant parts

and by adding some specificity with respect to the proposed action. It is also intended that this document be revised on a regular basis because of the rapidly changing nature of federal environmental law and regulation, particularly because of the rapidly emerging (and thus still not fully developed) regulation of federal facilities by states.

It should be noted that environmental standards and permit requirements usually appear in regulations and not in the laws themselves. Thus, more emphasis is placed on regulations and less on laws in this document.

Order of Precedence of Federal and State Environmental Laws and Regulations

Environmental regulation of federal facilities is governed by federal law. Most major federal environmental laws now include provision for regulation of federal activities that impact the environment. The activity to be regulated is usually an activity being carried out by an agency of the executive branch. The federal environmental law will also designate a specific agency, such as the U.S. Environmental Protection Agency (EPA) or the U.S. Nuclear Regulatory Commission (NRC), as the regulator, or the law will permit self-regulation. In addition, federal laws may provide for the delegation of the environmental regulation of federal facilities to the states or may directly authorize the environmental regulation of federal facilities by the states, through waivers of sovereign immunity. At Hanford, all these situations apply in varying degrees: the EPA has regulatory authority over Hanford facilities (where not authorized or delegated) and the NRC may have some future regulatory authority over some future Hanford facilities; the EPA has delegated regulatory authority to, shares regulatory authority with, or is in the process of delegating regulatory authority to, the State of Washington; and the State of Washington asserts its own independent regulatory authority under federal waivers of sovereign immunity.

As a legal matter at Hanford, applicable federal and state environmental standards must be met. As a practical matter, differences in language between federal law and the pursuant state laws and regulations may result in some differences in applicability and interpretation. These prospective events, however, need not concern us here. Guidance on specific applicability should be obtained from the DOE Richland Operations Office legal counsel.

Citation of Laws and Regulations

Laws and regulations may be cited both by their name and by their location in the appropriate document. Federal laws are most often cited as a public law (Pub. L. or PL) or by their location in the United States Code (U.S.C. or USC). Section numbers differ between the two, so it must be understood which is being cited. Federal regulations appear in the Code of Federal Regulations (CFR). Washington State laws are most often cited by their location in the Revised Code of Washington (RCW), and Washington State regulations are cited by their location in the Washington Administrative Code (WAC). Announcements of proposed and final federal regulations appear in the Federal Register (FR). Announcements of proposed and final Washington State regulations appear in the Washington State Register (WSR).

Specific Federal Laws Cited in the CEQ Regulations

Four federal laws are specifically cited in the CEQ regulations and deserve mention here. These are Section 309 of the Clean Air Act (42 U.S.C. 7609), the Fish and Wildlife Coordination Act (16 U.S.C. 661 et seq.), the National Historic Preservation Act (16 U.S.C. 470 et seq.), and the Endangered Species Act (16 U.S.C. 1531 et seq.). Section 309 of the Clean Air Act directs the EPA to review and comment on the environmental impacts of federal activities, including actions for which EISs are prepared. In addition to commenting on EISs, EPA rates every draft EIS prepared by a federal agency. EPA's comments are answered in the final EIS, but the EPA rating is usually not mentioned in an EIS. This latter fact should be known by the EIS preparers so that the EIS will be prepared in such a fashion as to avoid an unfavorable rating. The other three federal laws are often discussed in the chapter on the affected environment, rather than in the chapter on statutory and regulatory requirements. They should be discussed somewhere in the EIS and are discussed here for completeness.

6.1 Federal Environmental Laws

Significant federal environmental laws applicable to the Hanford Site include the following:

- National Environmental Policy Act (NEPA) (42 U.S.C. 4321 et seq.)
- Clean Air Act (CAA) as amended by the Clean Air Act Amendments of 1990 (42 U.S.C. 7401 et seq.)
- Clean Water Act (CWA) (33 U.S.C. 1251 et seq.)
- Safe Drinking Water Act (SDWA) (42 U.S.C. 300f et seq.)
- Native American Graves Protection and Repatriation Act. Public Law 101-601, November 16, 1990, (25 USC 3001 et seq.)
- Resource Conservation and Recovery Act (RCRA) as amended by the Hazardous and Solid Waste Amendments (42 U.S.C. 6901 et seq.)
- Federal Facilities Compliance Act (FFCA) (PL 102-386)
- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) as amended by the Superfund Amendments and Reauthorization Act (SARA) (42 U.S.C. 9601 et seq.).
- Endangered Species Act (16 U.S.C. 1531-1534)
- Fish and Wildlife Coordination Act (16 U.S.C. 661-666c)

- Bald and Golden Eagle Protection Act (16 U.S.C 668-668d)
- Migratory Bird Treaty Act (16 U.S.C 703-711)
- National Historic Preservation Act (16 U.S.C. 470-470w-6)
- Archaeological Resources Protection Act (16 U.S.C. 470aa-470ll)
- Archaeological and Historic Preservation Act (16 U.S.C. 469-469c)
- American Antiquities Act (16 U.S.C. 431-433)
- American Indian Religious Freedom Act (42 U.S.C. 1996).
- Native American Graves Protection and Repatriation Act (25 U.S.C. 3001 et seq.)
- Comprehensive Conservation Study of the Hanford Reach of the Columbia River (PL 100-605).
- Toxic Substances Control Act (TSCA) (15 U.S.C. 2601-2671)

In addition, the Atomic Energy Act (AEA) (42 U.S.C. 2011 et seq.), the Low-Level Radioactive Waste Policy Act (LLWPA) (42 U.S.C. 2021b et seq.), and the Nuclear Waste Policy Act (NWPA) (42 U.S.C. 10101 et seq.), while not environmental laws per se, contain provisions under which environmental regulations applicable to the Hanford Site may be or have been promulgated.

6.2 Federal and State Environmental Regulations

Activities of the federal government are ordinarily not subject to regulation by the states, unless specific exceptions are created by Congress. Exceptions with respect to environmental regulation have been created by Congress and provisions in several federal laws give to the states specific authority to regulate federal environmental activities. These waivers (or partial waivers) of sovereign immunity appear in Section 118 of the CAA, Section 313 of the CWA, Section 1447 of the SDWA, Section 6001 of RCRA, and Section 120 of CERCLA/SARA. The FFCA is an amendment to RCRA that makes the RCRA waiver of sovereign immunity more explicit. At the present time, most Washington State programs with respect to the environmental regulation of Hanford facilities are coordinated with EPA Region 10.

Federal and state environmental regulations that may apply to DOE operations at the Hanford Site have been promulgated under the CAA, CWA, SDWA, RCRA, CERCLA, SARA, AEA, LLWPA, NWPA, under other federal statutes, and under relevant state statutes. The Clean Air Act Amendments of 1990 will result in extensive revisions of federal and state air quality regulations. Specifically, a large list of hazardous air pollutants

will be brought under regulation and a more uniform state regulatory and permitting system under state implementation plans will result. Also, federal and state regulations relating to hazardous waste management continue to be promulgated under RCRA at a rapid rate.

Several of the more important existing federal and state environmental regulations are discussed briefly below. These regulations are grouped according to areas of environmental interest.

6.2.1 Air Quality

- 40 CFR 50, "National Primary and Secondary Ambient Air Quality Standards." EPA regulations in 40 CFR 50 set national ambient air quality standards (NAAQSs) for air pollutants including sulfur oxides, particulate matter, carbon monoxide, ozone, nitrogen dioxide, and lead. These standards are not directly enforceable; but other, enforceable regulations are based on these standards.
- 40 CFR 51-52, State Implementation Plans. EPA regulations in 40 CFR 51-52 establish the requirements for state implementation plans (SIPs) and record the approved plans. The SIPs are directed at the control of emissions from stationary sources and include state permits (see 40 CFR 70 below).
- 40 CFR 60, "Standards of Performance for New Stationary Sources." EPA regulations in 40 CFR 60 provide standards for the control of the emission of pollutants to the atmosphere. Construction or modification of an emissions source in an attainment area formerly required a prevention of significant deterioration of air quality (PSD) permit under 40 CFR 52. These permits will in the future become part of EPA's or the state's comprehensive air permit program (see 40 CFR 70 below).
- 40 CFR 61, "National Emission Standards for Hazardous Air Pollutants," (NESHAP); also 40 CFR 61 Subpart H, "National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities." EPA hazardous emission standards in 40 CFR 61 provide for the control of the emission of hazardous pollutants to the atmosphere, and standards in 40 CFR 61 Subpart H apply specifically to the emission of radionuclides from DOE facilities. Approval to construct a new facility or to modify an existing one may be required by these regulations. EPA has not yet delegated this approval authority to the State of Washington for the Hanford Site, but this delegation is likely to occur under the EPA's consolidated air permit program (see 40 CFR 70 below). The brief list of hazardous air pollutants presently regulated under 40 CFR 61 will be expanded pursuant to the Clean Air Act Amendments of 1990 (CAAA) and may include the 189 hazardous air pollutants listed in the CAAA.
- 40 CFR 70, "State Operating Permit Programs." These regulations provide for the establishment of comprehensive state air quality permitting programs that will replace

the existing fragmented programs. All major sources of air pollutants including hazardous air pollutants will be covered. Changes may be made in WAC 173-400 through 173-495 and in WAC 246-247 (see below).

- WAC 173-400 through 173-495, Washington State Air Pollution Control Regulations; General Regulation 80-7, Benton-Franklin-Walla Walla Counties Air Pollution Control Authority. Ecology air pollution control regulations, promulgated under the Washington Clean Air Act (RCW 70.94), appear in WAC 173-400 through 173-495. These regulations include emission standards, ambient air quality standards, and the new standards in WAC 173-460, "Controls for New Sources of Toxic Air Pollutants." The State of Washington has delegated much of its authority under the Washington Clean Air Act to the Benton-Franklin Counties Clean Air Authority.
- WAC 246-247, "Radiation Protection--Air Emissions." Washington Department of Health regulations in WAC 246-247 contain standards and permit requirements for the emission of radionuclides to the atmosphere from DOE facilities based on Ecology standards in WAC 173-480, "Ambient Air Quality Standards and Emission Limits for Radionuclides."

6.2.2 Water Quality

- 40 CFR 121, "State Certification of Activities Requiring a Federal License or Permit." These regulations provide for state certification that any activity requiring a federal water permit, i.e., an NPDES permit or a discharge of dredged or fill material permit, will not violate state water quality standards.
- 40 CFR 122, "The National Pollutant Discharge Elimination System" (NPDES). EPA regulations in 40 CFR 122 (and also in 40 CFR 125 and 129) apply to the discharge of pollutants from any point source into waters of the United States. These regulations also now apply to the discharge of storm waters and the discharge of runoff waters from construction areas over 5 acres in size into waters of the United States. NPDES permits may be required by 40 CFR 122. EPA has not yet delegated to the State of Washington the authority to issue NPDES permits at the Hanford Site.
- 40 CFR 141, "National Primary Drinking Water Regulations." EPA drinking water standards in 40 CFR 141 apply to Columbia River water at community water supply intakes downstream of the Hanford Site.
- 40 CFR 144-147, "Underground Injection Control Program" (UIC). EPA regulations in 40 CFR 144-147 apply to the underground injection of liquids and wastes and may require a permit for any underground injection. In Washington State, the EPA has approved Ecology regulations in WAC 173-218, "Underground Injection Control Program," to operate in lieu of the EPA program. The Ecology regulations provide standards and permit requirements for the disposal of fluids by well injection.

- 10 CFR 1022, "Compliance with Floodplain/Wetlands Environmental Review Requirements." DOE regulations in 10 CFR 1022 apply to DOE activities that are proposed to take place either in wetlands or in floodplains.
- 33 CFR 322-323, 40 CFR 230-233, Corps of Engineers Permits. Structures in the Columbia River and work in the Columbia River, as well as the discharge of dredged or fill material into the Columbia River, require Corps of Engineers permits under these regulations.
- WAC 173-160. Under WAC 173-160, DOE provides notification to Ecology for water-well drilling on the Hanford Site.
- WAC 173-216, "State Waste Discharge Permit Program." Ecology regulations in WAC 173-216 establish a state permit program for the discharge of waste materials from industrial, commercial, and municipal operations into ground and surface waters of the state. Discharges covered by NPDES or WAC 173-218 permits are excluded from the 216 program. DOE has agreed to meet the requirements of this program at the Hanford Site for discharges of liquids to the ground.
- RCW 75.20.100, "Hydraulic Projects Act," WAC 220-110. As a matter of comity, DOE will obtain hydraulic project approval from the State Departments of Fisheries and Wildlife to construct any form of hydraulic project or perform work that will divert, obstruct, or change the natural flow of the Columbia River.
- WAC 332-30, River Bottom Lease. DOE will obtain a river bottom lease from the Washington Department of Natural Resources for any structures that may be placed in the bottom of the Columbia River.

6.2.3 Solids

- 40 CFR 260-268 and 270-272, "Hazardous Waste Management." EPA RCRA regulations in 40 CFR 260-268 and 270-272 apply to the generation, transport, treatment, storage, and disposal of hazardous wastes (but not to source, by-product, or special nuclear material, i.e., not in general to radioactive wastes), and apply to the hazardous component of hazardous radioactive mixed wastes (but not to the radioactive component) owned by DOE. RCRA regulations require treatment of many hazardous wastes before they can be disposed of in landfills (land disposal restrictions). RCRA permits are required for the treatment, storage, or disposal of hazardous wastes. The regulations also require cleanup (corrective action) of any RCRA facility from which there is an unauthorized release before a RCRA permit may be granted. Most of the authority to administer the RCRA program has been delegated by EPA to the State of Washington, except for corrective action.
- 40 CFR 280-281, Underground Storage Tanks. EPA regulations in 40 CFR 280-281 apply to underground storage tanks and may require permits for new and existing

tanks containing petroleum or substances regulated under CERCLA (except for hazardous wastes regulated under RCRA). EPA has authorized Washington State to administer this program under RCW 90.76 and WAC 173-360.

- 40 CFR 300, "National Oil and Hazardous Substances Pollution Contingency Plan." EPA CERCLA regulations in 40 CFR 300 apply to the cleanup of inactive hazardous waste disposal sites, to the cleanup of hazardous substances released into the environment, to the reporting of hazardous substances released into the environment, and to natural resource damage assessments. On November 3, 1989, the Hanford Site was placed on the EPA's National Priorities List (NPL). Placement on the list requires DOE, in consultation with EPA and Washington State, to conduct remedial investigations and feasibility studies leading to a record of decision on the cleanup of inactive waste disposal sites at Hanford. Standards for cleanup under CERCLA are "applicable or relevant and appropriate requirements" (ARARs) which may include both federal and state laws and regulations. In anticipation of Hanford's being placed on the NPL, DOE, EPA, and Ecology signed the Hanford Federal Facility Agreement and Consent Order (Tri-Party Agreement) on May 15, 1989. This agreement describes the cleanup responsibilities and authorities of the three parties under CERCLA (and RCRA), and also provides for permitting of the treatment, storage, and disposal of hazardous wastes under RCRA. A revised Tri-Party Agreement was signed on January 25, 1994. These revisions were occasioned by substantial changes in plans for dealing with high-level wastes stored in underground tanks at Hanford.
- WAC 173-303, "Dangerous Waste Regulations." The EPA has authorized the State of Washington through Ecology to conduct its own dangerous waste regulation program in lieu of major portions of the RCRA interim and final permit program for the treatment, storage, and disposal of hazardous wastes. Ecology is also authorized to conduct its own program for the hazardous portion of radioactive-mixed wastes. However, EPA has retained its authority to administer those sections of the hazardous waste program mandated by the Hazardous and Solid Waste Amendments to RCRA, specifically corrective action. The state regulations include both standards and permit requirements.

6.2.4 Species Protection

- 50 CFR 10-24, 222, 225-227, 402, and 450-453, Species Protection Regulations. Regulations of the Endangered Species Act, the Bald and Golden Eagle Protection Act, and the Migratory Bird Treaty Act in 50 CFR 10-24 apply to the protection of these species on the Hanford Site. Regulations in 40 CFR 222, 225-227, 402, and 450-453 apply to endangered or threatened species. In addition, the Fish and Wildlife Coordination Act requires consultation with the U.S. Fish and Wildlife Service if any body of water over ten acres in size is to be modified by a federal agency for any purpose. The purpose of this consultation is to prevent loss and damage to wildlife resources.

6.2.5 Historic Preservation

- 36 CFR 800, 25 CFR 261, 43 CFR 3, 36 CFR 296, and 43 CFR 7, Historic Preservation Regulations. Requirements of the National Historic Preservation Act in 36 CFR 800; 36 CFR 18 Leases and Exchanges of Historic Property, Public Law 95-515 (16 USC 470h-3); 36 CFR 60 National Register of Historic Places, National Historic Preservation Act (16 USC 470 et seq.); 36 CFR 63 Determination of Eligibility for Inclusion in the National Register of Historic Places, National Historic Preservation Act (16 USC 462); 36 CFR 79 Curation of Federally Owned and Administered Archaeological Collections (16 USC 470 et seq.); the American Antiquities Act in 25 CFR 261 and 43 CFR 3, the Archaeological Resources Protection Act and the American Indian Religious Freedom Act in 36 CFR 296 and 43 CFR 7, and the Native American Graves Protection and Repatriation Act, Public Law 101-601, November 16, 1990 (25 USC 3001 et seq.) apply to the protection of historic and cultural properties, including both existing properties and those discovered during excavation and construction.

6.2.6 Land Use

The Comprehensive Conservation Study of the Hanford Reach of the Columbia River (PL 100-605) required the Secretary of the Interior, in consultation with the Secretary of Energy, to conduct a study of the Hanford Reach of the Columbia River that included identification and evaluation of geologic, scenic, historic, cultural, recreational, fish, wildlife, and natural features of the reach. The Secretary of the Interior was also directed by Congress to examine alternatives for the preservation of these features. A draft study report was published in June 1992: *Hanford Reach of the Columbia River, Comprehensive River Conservation Study and Environmental Impact Statement*. This study may lead to recommendations to Congress that the Hanford Reach of the Columbia River be designated a wild or scenic river the Wild and Scenic River Act.

6.2.7 Other

- 40 CFR 191, "Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes." EPA regulations in 40 CFR 191 provide environmental standards for the management, storage, and disposal of spent nuclear fuel, high-level radioactive wastes, and transuranic radioactive wastes at high-level or transuranic waste disposal sites. EPA continues to work on a revision to subpart B of those regulations, which were remanded by the courts for EPA's reconsideration.
- 40 CFR 700-799, Toxic Substances Control Act Regulations. EPA's regulations in 40 CFR 700-799 implement TSCA and, in particular, regulate polychlorinated biphenyls and dioxins and partially regulate asbestos.
- 40 CFR 1500-1508, Regulations of the Council on Environmental Quality (CEQ) that implement NEPA. The CEQ regulations in 40 CFR 1500-1508 provide for the

preparation of environmental documentation on any federal action impacting the environment, and require federal agencies to prepare an environmental impact statement (EIS) on any major federal action significantly affecting the quality of the human environment.

- 10 CFR 1021, "Compliance with the National Environmental Policy Act." DOE regulations in 10 CFR 1021 implement the National Environmental Policy Act (NEPA) and the Council on Environmental Quality's NEPA regulations in 40 CFR 1500-1508.
- 49 CFR 171-179, "Hazardous Materials Regulations." Department of Transportation regulations in 49 CFR 171-179 apply to the handling, packaging, labeling, and shipment of hazardous materials offsite, including radioactive materials and wastes.

6.3 DOE Orders

The most significant DOE orders with respect to environmental compliance at Hanford are the 5400 and 5480 series, beginning with DOE Order 5400.1, "General Environmental Protection Program," and DOE Order 5480.1B "Environment, Safety, and Health Program for Department of Energy Operations." These orders cover environmental protection, safety, and health protection standards; hazardous and radioactive-mixed waste management; cleanup of retired facilities; safety requirements for the packaging and transportation of hazardous materials; safety of nuclear facilities; radiation protection; and other standards for the safety and protection of workers and the public. Regulations and standards of other federal agencies and regulatory bodies, as well as other DOE orders, are incorporated by reference into DOE orders. Some DOE orders related to the environment are being prepared for promulgation as regulations in the CFR.

Other DOE orders that are important with respect to environmental compliance include DOE Order 5820.2A, "Radioactive Waste Management."

6.4 Permits

The DOE holds an NPDES permit from EPA Region 10 for the discharge of nonradioactive liquids to the Columbia River. On June 28, 1985, the DOE applied for renewal of this permit. The original permit is still in effect pending renewal. Applications for new discharges to the Columbia River have been filed or are being prepared.

The DOE holds a PSD permit from EPA Region 10 for the discharge of oxides of nitrogen to the atmosphere from the PUREX and Uranium Oxide Plants.

The DOE holds approvals for construction of air emission facilities and approvals of alternate air emission limits issued by the Benton-Franklin Counties Clean Air Authority.

The DOE received a NESHAP authorization on November 28, 1986, from EPA Region 10 for construction of the transportable grout facility. The DOE received a Radioactive Source Registration permit from the Washington Department of Health on August 15, 1989, for radioactive emissions from Hanford Site operations.

Federal air quality permits are likely to be consolidated in the future in response to the Clean Air Act AMENDMENTS OF 1990.

The DOE holds interim status for the operation of hazardous waste management facilities by virtue of having submitted a RCRA Part A application to EPA on November 18, 1980. On November 6, 1985, the DOE submitted a RCRA Part B application to EPA Region 10 and to the WDOE for the storage, treatment, and disposal of hazardous wastes at Hanford. Supplemented and revised RCRA applications have been submitted either to Ecology, to the EPA, or to both as appropriate.

DOE has asserted a federally reserved water withdrawal right with respect to its Hanford operations. Current activities utilize water withdrawn under the Department's federally reserved water right.

6.5 Environmental Standards for Protection of the Public

Numerical standards for protection of the public from releases to the environment have been set by the EPA and appear in the CFR.

Standards in 40 CFR 61.92 apply to releases of radionuclides to the atmosphere from DOE facilities and state that:

Emissions of radionuclides [other than radon-220 and radon-222] to the ambient air from Department of Energy facilities shall not exceed those amounts that would cause any member of the public to receive in any year an effective dose equivalent of 10 mrem/yr.

Standards in 40 CFR 141.16 apply indirectly to releases of radionuclides from DOE facilities (and also non-DOE facilities) to the extent that the releases impact community water systems:

The average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water shall not produce an annual dose equivalent to the body or any internal organ greater than 4 millirem/year.

Also, maximum contaminant levels in community water systems of 5 picocuries per liter of combined radium-226 and radium-228, and maximum contaminant levels of 15 picocuries per liter of gross alpha particle activity, including radium-226 but excluding radon and uranium, are specified in 40 CFR 141.

40 CFR 141 also specifies maximum concentrations of some chemical contaminants in drinking water, including arsenic, lead, mercury, nitrate, and some organic compounds.

EPA regulations in 40 CFR 264 contain numerical standards for protection of the public from releases of hazardous wastes from hazardous waste disposal sites.

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